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ABSTRACT

The instructor's guide and curriculum guide contained in this packet are designed to help teachers provide future automotive technicians with some of the electronic skills they will need to service cars of the future. The instructor's guide is designed to help teachers make certain that each student gets the most benefit possible out of both the student's manual and the learning activities at the training stations. It provides a list of essential elements and guidelines for adapting the material for students with special needs. It also contains answers to exercises and unit test questions, a work sheet to help in coordinating work experiences with the assignments, and unit tests for each unit. The seven units of the student's manual cover the following topics: introduction, safety and tools, basic electricity and electronics, engine electrical systems, body electrical systems, engine electronic control systems, and vehicle control systems. The curriculum guide contains the following: information about the course; an instructional key; lists of essential elements for all trade and industrial courses and essential elements for automotive technicians; an outline of basic skills applications; and assignment titles, objectives, and related essential elements for the units of the course. (KC)

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Automotive Technician II for ICT

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IMC

Instructor's Guide

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Automotive Technician II for ICT

Instructor's Guide

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Prepared by

Troy Notgrass

and

Bob Snider

Published by

The University of Texas at Austin
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Division of Continuing Education

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COMPLIANCE STATEMENT

TITLE VI, CIVIL RIGHTS ACT OF 1964; THE MODIFIED COURT ORDER, CIVIL ACTION 5281, FEDERAL DISTRICT COURT, EASTERN DISTRICT OF TEXAS, TYLER DIVISION

Reviews of local education agencies pertaining to compliance with Title VI Civil Rights Act of 1964 and with specific requirements of the Modified Court Order, Civil Action No. 5281, Federal District Court, Eastern District of Texas, Tyler Division are conducted periodically by staff representatives of the Texas Education Agency. These reviews cover at least the following policies and practices:

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(3) nondiscrimination in extracurricular activities and the use of school facilities;

(4) nondiscriminatory practices in the hiring, assigning, promoting, paying, demoting, reassigning, or dismissing of faculty and staff members who work with children;

(5) enrollment and assignment of students without discrimination on the basis of race, color, or national origin;

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Foreword

This publication is one of a series of self-contained instructional materials for trade and industrial students. Each student who uses this material can work at his or her own pace, learning those things that best fit her or his specific needs. The design of the material makes it possible to relate work experience on the job to information studied at school.

Although the material is individualized, it should be used under the supervision of an instructor. For that reason, two basic publications are offered, a student's manual and an instructor's guide.

The **student's manual** is for the use of the person in training. Each unit includes appropriate information, objectives to be met, and exercise questions that help the student meet those objectives.

The **instructor's guide** provides information to the instructor on how to use the material to the best advantage of the student, answers to exercise questions and unit test questions, one set of unit tests, and a work sheet.

Every effort has been made to produce a publication that addresses the unique needs of our current student population. Students with limited English proficiency (LEP), as well as handicapped, educationally disadvantaged, and nontraditional students, may require modification of the material in this publication. The professional staff of EIMC will gladly work with any instructor having these students to how how the instructional material can be adapted for specific individualized instruction. Consult local, state, and federal agencies that offer assistance and guidance and that can provide sound recommendations for productive classroom management.

Kathryn R. Allen, Ph.D.
Director, Extension Instruction
and Materials Center

Preface

The modern automobile has become very efficient and economical to operate as result of extensive use of electronics. Although the electronics used in automobiles is very reliable, some problems still occur and some of the parts do wear out. This manual has been written to prepare the future automotive technician with some of the electronic skills they will need to service these automobiles.

Section C was written to provide the student with the basics in electrical and electronic theory. It should be studied in the sequence in which it was written. The student should have a good grasp of Section C material before trying to cover any of the following sections. The lessons in the following sections can be studied in any order after completing Section C.

Since the automotive technician will rarely deal with a printed circuit board, the laboratory part of the lessons was designed using jumper wires instead of a breadboard. The students' retention and confidence in the lesson material will be improved when they complete the laboratory or workbook portion of the lessons.

Although much of the automotive electronics used today on the cutting edge of technology, the author feels the material in Section C is adequate for a beginning automotive technician. The successful completion of this material will help in providing a more secure and profitable position for the new automotive technician.

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Acknowledgments

The Extension Instruction and Materials Center gratefully acknowledges the contribution of the advisory committee members have made to the revision of this manual. Members of the committee are: Mr. Mike Deanovich, Regional College Coordinator, General Motors Corporation (STG), Deer Park, Texas; Mr. Ron Reed, Service Training Instructor, Gulf States Toyota, Houston, Texas; Mr. Bill Szelag, GM Service Technology Group, General Motors Training Center, Garland, Texas; Mr. Dennis Tarkington, Technical Services Manager, Ford Parts and Services Division, Carrollton, Texas; Mr. Ray Vansickle, Training Instructor, Ford Parts and Service, Houston, Texas; Mr. Marvin Johnson, Instructor, Brookhaven College, Farmers Branch, Texas; Mr. Phillip Anderson, Automotive Technology Instructor, Colorado City High School, Colorado City, Texas; and Mr. Ray Castellow, Automotive Technology Instructor, South Grand Prairie High School, Grand Prairie, Texas.

We would also like to acknowledge with grateful appreciation the cooperation and generosity of A.W. Sperry Instruments, Inc., Chicago Pneumatic, Ford Motor Company, General Motors Corporation, Proto Tools, and Toyota Motor Company in supplying many illustrations, charts, and technical data useful in the development of this publication.

Notes for the Instructor

The student's self-contained manual is designed for use in presenting related technical information to (1) groups of trade and industrial students with a variety of vocational objectives and (2) homogeneous groups in which the learning levels of individuals vary considerably. The manual is not intended to be used as a type of correspondence course, but must be used by students under the direct supervision of an instructor.

The instructor's guide is designed to help the instructor make certain that each student gets the most benefit possible out of both the student's manual and what is learned at the training station. It provides answers to exercises and unit test questions. It also provides a work sheet to help in coordinating work experiences with the assignments.

The instructor should keep all answers to questions. The actual unit tests can be removed from this book to make them easier to use or reproduce. For greater convenience, this manual is punched for notebook use and held together by staples only.

Required Laboratory Supplies

The following supplies are necessary for the student to work the laboratory experiments. Working the laboratory experiments will not endanger the student or others in the classroom if the directions in the experiments are followed. No high voltages are required nor are acids used. About $50.00 is required to purchase these supplies at a Radio Shack or other electronic supplier.

1 battery holder for four dry cell batteries
4 dry cell batteries
1 package of 10 jumper leads with alligator clips
1 DVOM (digital multimeter)

7 feet of insulated light-duty wire
6 clips (the clips should match the wire size)
1 roll of electrical tape
1 crimping tool (with features to cut wire and strip insulation)
3 nails about 2 inches long

1 100 μF or higher capacitor
4 silicon diodes
1 light-emitting diode (LED)
1 comparator
1 socket for the comparator
1 variable resistor (10 kΩ potentiometer)
1 47 Ω resistor
1 120 Ω resistor
1 220 Ω resistor
1 330 Ω 5% 1/4 watt resistor
1 470 Ω 5% resistor

1 680 Ω resistor
1 1 kΩ resistor
1 2.2 kΩ 5% resistor
1 4.7 kΩ 5% resistor
1 9 kΩ 5% resistor
1 10 kΩ resistor
Miscellaneous paper, wooden pencil or other stick for a pointer

Academic Background Required

Students must have the correct background in order to succeed in this field.

English. Students should have a good background in English. They should be able to read at the eleventh-grade level in order to understand the schematics, specifications, etc.

Mathematics. The student should have a good background in mathematics. Successful completion of two years of algebra is desirable.

Science. Background courses in chemistry and physics are beneficial to automotive electronic technicians.

Aptitudes. Students should have a high mechanical aptitude and a high degree of manual dexterity.

This information may be used in counseling students who express a desire to train in this field. It also could be useful to school counselors who may have the opportunity to guide students toward a vocational program.

Contents

Automotive Technician II for ICT is designed as a self-study text that does not rely upon a knowledgeable instructor and requires laboratory studies. Each laboratory experiment should be completed as the student completes the assignment preceding it. The student's manual is organized to guide the student through the fundamentals of electricity and electronics. After developing the fundamentals, the student will learn the application of the principles through the study of sensors and actuators. The actuators will then be applied to the various body electrical systems, electronic engine control systems, and vehicle control systems. Each assignment in the fundamentals section (Unit C) builds on the knowledge students have gained from the previous assignments. The assignments within Unit C are developed sequentially. Therefore, students should study the assignments in order. Assignments in all succeeding units may be studied in any sequence. When they have completed this course, they will be adequately prepared to enroll in an automotive technician's course at the postsecondary level or to continue in the occupation as an automotive technician.

Organization

The student's manual is designed to use as many fundamental teaching principles as possible. Each part of the manual is based on one of these principles.

Objectives. The first fundamental teaching principle is that the student should be *informed* at the outset what should be learned in the assignment. This is done through a statement of objectives at the beginning of each assignment. These are performance objectives that can be tested on completion of the assignment.

Technical information. The second teaching principle is that technical information should be presented in *complete, but concise form.* This information is presented step-by-step, going from the simple to the complex, from the known to the unknown, thus making learning easy. Of the four teaching principles discussed here, this is by far the most important. The biggest favor you can do for the student is to persuade her or him that, if she or he learns the information presented, the grades will take care of themselves.

Exercise. The third teaching principle is that technical information is better learned if it can be *applied* as soon as possible after presentation. This is done through exercise questions for each assignment. The questions are phrased to emphasize key points, to aid in learning facts that must be memorized, or to provoke thought about and evaluation of the technical information. You should emphasize to students that both the objectives and the technical information should be read before any attempt is made to answer questions in the exercise. Answers may also be useful when helping a student who is having difficulty with an assignment exercise. Students' answers need not be stated in exactly the same words used in the assignment information.

Laboratory experiments and workbook activities. Information learned and applied in the technical information and exercise sections of the lesson is *reinforced* through the use of laboratory experiments or workbook activities. Each of the experiments or workbooks is designed around the information studied in the assignment. They are practical applications that require the student to make evaluations and decisions based on principles discussed in the assignment. The instructor's guide has a copy of the laboratory experiments, and when predictable results are expected, those results are given in this guide

Tests. A fourth teaching principle is carried out in the instructor's guide. The principle is that the effectiveness of the assignment should be *evaluated.* This is done through a unit test that is keyed to the objectives stated for the assignments within each unit. These tests should be given on completion of the unit. Answers to tests provide a reference for grading. *You should retain all answers for obvious reasons.*

Tests and Work Sheet

The last section of this instructor's guide has been placed after a divider page so that the unit tests and the work sheet can be removed for use with individual students or for reproduction. You may reproduce these pages *without permission.*

The work sheet is provided for your convenience in (1) planning how job experience is to be matched to related instruction in the student's manual and (2) keeping daily records as the student progresses through the year. The assignments are coded and can be easily listed opposite the desired jobs. Also, space is provided for other records you may wish to include on the work sheet.

Essential Elements

§75.88 Trade and Industrial Education

(a) The elements in this subsection are **common to all trade and industrial courses** unless otherwise indicated and shall be included in each course at the appropriate level. They are described here to preclude repetitions in each course. Every school offering trade and industrial education shall provide courses which include the following essential elements:

(1) *Leadership* concepts and skills. The student shall be provided opportunities to:

(A) demonstrate skills, characteristics, and responsibilities of leaders and effective group members;
(B) demonstrate a knowledge of parliamentary procedure principles;
(C) plan and conduct leadership activities; and
(D) prepare for effective citizenship and for participation in our democratic society.

(2) Concepts and skills related to successful *employment* and/or *postsecondary training*. The student shall be provided opportunities to:

(A) identify employment opportunities and preparation requirements in chosen fields;
(B) identify effective methods to secure and terminate employment;
(C) demonstrate effective communication skills both oral and written and follow through on assigned tasks;
(D) demonstrate dependability and punctuality;
(E) demonstrate productive work habits and attitudes;
(F) understand the importance of taking pride in the quality of work performed;
(G) recognize the dignity in work;
(H) develop skills in planning and organizing work;
(I) apply required methods and sequences when performing tasks;
(J) apply principles of time management and work simplification when performing assigned tasks;
(K) identify ethical practices and responsibilities; and
(L) understand the importance of the application of organizational policies and procedures.

(3) Concepts and skills associated with *entrepreneurship*. The student shall be provided opportunities to:

(A) identify opportunities for business ownership;
(B) understand the risk and profit motive factor;
(C) understand the elements and advantages of the free enterprise system; and

(D) explain the role of small business in the free enterprise system.

(4) Concepts and skills related to *safety and safe working conditions*. The student shall be provided opportunities to identify and apply safe working practices to all training situations.

(5) Concepts and skills associated with *human relations and personality development*. The student shall be provided opportunities to:

(A) understand the importance of maintaining good health and proper appearance for effective job performance;
(B) understand oneself and others;
(C) exercise self-control;
(D) accept and use criticism;
(E) recognize basic human relationships as they relate to business success; and
(F) demonstrate characteristics for successful working relationships.

(6) Concepts and skills related to *personal and business management*. The student shall be provided opportunities to:

(A) explain how management assists in reaching personal and family goals;
(B) explain the management process;
(C) describe the role of management in controlling stress;
(D) identify and understand personal checking accounts;
(E) identify and understand personal loan application processes;
(F) identify and understand different financial institutions;
(G) identify the role and functions of business management;
(H) understand the lines of authority; and
(I) identify effective supervisory techniques.

(7) Concepts and skills associated with the *specific occupation* being taught. The student shall be provided opportunities to:

(A) understand the basic concepts of and develop proficiency in the occupational area for which instruction/training is provided;
(B) develop a fundamental understanding of mathematical principles and scientific procedures;
(C) understand terminology utilized;
(D) identify tools, equipment, and materials used; and
(E) develop and demonstrate appropriate techniques for the selection, use, maintenance, and storage of tools, equipment, and materials.

(gg) *Automotive technician* (2-3 units) shall include the essential trade and industrial elements and concepts associated with automobile mechanics. The student shall be provided opportunities to:

(1) understand the functions of and analyze malfunctions in the automobile components;
(2) read and interpret appropriate repair and labor manuals;
(3) understand the basic fundamentals of the automobile engine and repair internal systems;
(4) understand, service, repair, and/or replace carbureted fuel systems, engine cooling systems, emission control systems, electrical and electronic equipment, power trains, chassis, and heating and air-conditioning systems; and
(5) understand the fundamentals of gasoline fuel injection and diesel engine fuel injection systems.

Instructional Key

Assignment	Title	Essential Elements
Unit A:	**Introduction**	
A-1	How to Use This Manual	
A-2	Occupational Outlook	(a)(2)(A)
A-3	Owning Your Own Business	(a)(3)(A–D)
Unit B:	**Safety and Tools**	
B-1	Shop Safety	(a)(4)
B-2	Hand Tools	(a)(7)(D)
B-3	Measuring Tools	(a)(7)(D)
B-4	Power Tools and Equipment	(a)(7)(D)
Unit C:	**Basic Electricity and Electronics**	
C-1	Fundamentals of Electricity	(gg)(1–3)
C-2	Circuit Analysis	(gg)(1-3)
C-3	Conductors and Resistors	(gg)(1-3)
C-4	Magnetism	(gg)(1–3)
C-5	Schematics (Electrical Road Maps)	(gg)(1–3)
C-6	AC and Computer Signals	(gg)(1–3)
C-7	Semiconductor Diodes	(gg)(1–3)
C-8	Transistors	(gg)(1–3)
C-9	Computer Circuits	(gg)(1–3)

Unit D: Engine Electrical Systems

D-1	The Battery	(gg)(1-4)
D-2	The Charging System	(gg)(1-4)
D-3	The Cranking System	(gg)(1-4)

Unit E: Body Electrical Systems

E-1	Body Lights, Switches, and Related Systems	(gg)(1, 2, & 4)
E-2	Instrument Panel	(gg)(1–4)
E-3	Vehicle Restraint Systems	(gg)(1, 2, & 4)

Unit F: Engine Electronic Control Systems

F-1	Automotive Sensors	(gg)(1, 2 & 4)
F-2	Engine Fuel Delivery Systems	(gg)(1, 2, 4, & 5)
F-3	Ignition Systems	(gg)(1, 2, 4, & 5)
F-4	Emission Control Systems	(gg)(1, 2, 4, & 5)

Unit G: Vehicle Control Systems

G-1	Cruise Control	(gg)(1, 2, & 4)
G-2	Electronic Gearshift Transmissions	(gg)(1, 2, & 4)
G-3	Antilock Brake Systems	(gg)(1, 2, & 4)

Basic Skills Applications

Language Arts E.E. §75.61	(a)(4)(C)	(a)(4)(I)	(b)(4)(C)	(b)(4)(G)	(c)(4)(D)
Assignment Number	C-6	C-7	C-9	C-2	C-7
Mathematics E.E. §75.63	(c)(1)(B)	(c)(3)(C)	(c)(4)(C)	(e)(2)(F)	(e)(3)(C)
Assignment Number	C-2	C-7	C-1	C-1	C-7
Science E.E. §75.64	(b)(7)(C)	(c)(7)(B)	(d)(2)(C)	(m)(2)(B)	(p)(2)(A)
Assignment Number	C-2	C-4	F-4	C-8	C-1
Social Studies E.E §75.68	(b)(3)(D)	(c)(5)(L)	(d)(4)(E)	(k)(2)(B)	(k)(3)(A)
Assignment Number	A-3	(A-3)	F-4	C-2	F-3

Language Arts E.E.	**75.61**
(a)(4)(C)	Expand vocabulary
(a)(4)(I)	Draw conclusions and make inferences
(b)(4)(C)	Recognize relevant details
(b)(4)(G)	Evaluate and make judgments
(c)(4)(D)	Perceive cause and effect relationships

Mathematics E.E.	**75.63**
(c)(1)(B)	Use scientific notation
(c)(3)(C)	Find percent and percentage
(c)(4)(C)	Use metric and customary units
(e)(2)(F)	Use formulas to solve probems
(e)(3)(C)	Identify and graph functions

Science E.E.	**75.64**
(b)(7)(C)	Compare atomic structures of simple elements
(c)(7)(B)	Compare the functions of electronic circuits
(d)(2)(C)	Explore magnetic and electrical interactions
(m)(2)(B)	Examine environmental science principles
(p)(2)(A)	Organize thought processes to accomplish goals (applications of electronics, photography)

Social Studies E. E.	**75.68**
(b)(3)(D)	Explain the development and importance of new business and labor organizations
(c)(5)(L)	Explain the positive aspects and effects of American Capitalism upon the world
(d)(4)(E)	Analyze environmental issues associated with urban growth
(k)(2)(B)	Apply the strategies of problem solving
(k)(3)(A)	Draw inferences from data

Adapting Instruction for Special Needs Students*

The primary purpose of this unit is to provide the vocational educator with teaching strategies and techniques that will be useful when instructing students with special needs. It is important to remember that the methods and approaches used by educators when instructing non-special needs students may not be very effective with students who have special needs. Therefore, **individualizing** instruction becomes vitally important in the successful instruction of special learners.

Learning Styles

Each special learner has unique needs, and these needs affect how the student can best learn. For example, if a student is blind or has difficulty with "visual" learning, the instructor should stress the learner's senses of hearing and touch. If the student is deaf, the instructor should involve the learner's sense of sight. Therefore, the manner in which a student with special needs learns ceases to be a preference, but becomes instead a **necessity**. Further, one of the main philosophies behind individual learning styles is that learning should be a pleasant and successful experience. Educators, therefore, need to adjust their style of teaching to allow students the benefit of learning in their preferred manner.

The following are methods an educator can use to identify a student's learning style.

1. **Informal observation.** One of the simplest and possibly best ways to identify a student's learning style is through informal observation. By observing the student as he or she negotiates classroom/laboratory learning activities, the educator can collect valuable information with regard to the student's learning style. For example, the educator may observe that a disadvantaged student answers questions in class and does well with hands-on activities but repeatedly fails written exams. If the primary intent of the instruction is to teach vocational skills rather than reading and writing skills, the instructor could modify his or her style of teaching by allowing the student to take oral and/or hands-on exams.

2. **Teacher consultation.** Other teachers (e.g., special education teachers, resource room teachers, support personnel, paraprofessionals, and other vocational education teachers) can be an excellent source of information regarding a student's learning style.
3. **Student/parent interviews.** Interviewing the student and student's parents/guardians can result in valuable insights as to the student's best learning modes.
4. **Standardized inventories.** Standardized inventories provide an alternative for students who are shy or uncomfortable during a personal interview. Information received from interest, personality, and learning style inventories can provide valuable information with regard to the student's learning style.

Instructional Strategies

Once the student's vocational goals, learning capability, and preferred learning style have been identified, the educator can begin to experiment with a **variety** of teaching techniques and instructional materials. When determining the teaching technique and instructional material best suited to meet a student's unique needs, it is important for the educator to be patient, open-minded, and flexible. Not every instructional technique and/or material can be used successfully with each learner. In addition, the educator should not hesitate to enlist the support of other instructors, school counselors, student aides, paraprofessionals, volunteers from the community, itinerant teachers, and/or interpreters. This pooling of efforts can result in increased student learning because of the variety of approaches and personal attention which can be brought to the classroom or laboratory.

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* **Note:** Adapted from the *Vocational Special Needs Teacher Training Curriculum*, developed at Texas A&M University and available through the Extension Instruction and Materials Center, The University of Texas at Austin. See that publication for additional information and references on special needs students in vocational classrooms.

General Guidelines and Instructional Strategies

The following are general guidelines and instructional techniques which an educator can use to help meet a special needs learner's unique needs and learning style:

1. **Orientation.** Students with special needs may need additional orientation with regard to (a) the relevancy of their individualized goals, (b) class procedures, (c) safety, etc.

2. **Flexible pacing.** Students with special needs can exhibit different rates of learning. The educator should provide flexibility in pacing of instruction and assignments to meet the various needs of learners. In general, students with special needs should be individually paced to maintain their progress and interest, yet avoid the frustrations and failure that undue pressure may cause.

3. **Demonstration.** The demonstration method can be very effective in introducing a new skill to a learner with special needs.

4. **Breaking material into small distinct steps.** As a general rule, it is important for the educator to break a learning concept into small distinct steps. In this way, the educator can best identify where the student is experiencing difficulty.

5. **Positive environment and feedback.** In general, students with special needs lack confidence and a positive self-concept. This is primarily due to their not having had much success in life. In addition, the few successes special learners do have usually result in little, if any, positive reinforcement (i.e., praise, reward, and/or encouragement). Therefore, it is incumbent upon educators to create a positive, nonthreatening learning environment for their students and to make generous use of positive feedback when the student experiences success. Constructive criticism **should not** be avoided; however, it should be given in a positive manner (i.e., students should understand that their behavior or product is what's being criticized and **not** their worth as a human being). Finally, all students must learn that mistakes and constructive criticism are a normal and expected part of life.

6. **Use of peer tutors, college students, and volunteers.** Peer tutors, college students, and volunteers can greatly assist a vocational educator's work with special learners by (a) helping with individualized instruction, (b) providing positive role models, (c) increasing student participation, (d) increasing the special learner's success experiences, (e) increasing the student's confidence and self-esteem, and (f) improving the special learner's social and academic skills. In addition, peer tutors, college students, and volunteers can receive teaching experience and the satisfaction of helping individuals with special needs progress.

7. **Flexible grouping.** The educator can integrate special needs learners into groups of various sizes (according to the students' goals, interests, or ability levels) and use peer tutors, college students, and volunteers for assistance. Using flexible grouping (a) allows the teacher more time to work among the students; (b) allows the teacher to individualize instruction, tasks, and assignments to meet the needs of students in a specific group; (c) provides special needs learners with an opportunity to work with peers and establish positive interpersonal and working relationships with them; (d) serves as a motivating factor for special needs learners because the individualized nature of the group work does not become threatening or frustrating but allows students an opportunity to work at their own pace through their strongest learning style; (e) allows teachers to arrange for instruction for the entire class, small group discussions, project groups, and small remedial sessions so that instruction will be diversified and more meaningful for all students; and (f) it allows the teacher to modify the task or assignment for a small group of students with specific needs, as in the case of learners who have a physical disability.

8. **Providing field trips and job site visits.** Scheduled field trips and job site visits can give all learners a firsthand look into the real world of work. By "shadowing" workers in a particular occupational area, students can gain helpful insights into their own career decision, and can readily observe how his/her vocational training will be used in the world of work.

9. **Use of media.** Media can embellish instruction by (a) assisting the teacher in presenting the proficiency or skill requirements for a specific job; (b) reinforcing concepts presented in a classroom, laboratory, or demonstration activity; (c) providing a vehicle for special needs learners to show what they have learned; (d) providing a valuable source of remedial assistance; (e) providing simulated learning experiences; (g) allowing special needs students to learn through their strongest style; and (h) adding variety to the instructional program. Examples of media include computer-assisted instruction (CAI), 16mm films, filmstrips, flip charts, overhead transparencies, tape recorders, records, posters, magazines, and diagrams.

10. **Use of student-teacher contracts.** Student-teacher contracts can be excellent tools to help learners with special needs achieve their vocational goals. Use the following guidelines to develop and implement a student-teacher contract.

(1) Decide on the task or project.
(2) Specifically state the requirements.
(3) Determine the minimum acceptable accuracy.
(4) Set a time limit—initially, short assignments and short time periods are usually best.
(5) Identify consequences.
(6) Discuss contract with student and support personnel.
(7) Have all parties sign the contract.
(8) Give positive reinforcement if the terms of the contract are satisfactorily met.
(9) Analyze uncompleted contracts to determine the causes.
(10) Develop new contracts cooperatively.

Specific Guidelines and Instructional Strategies

The following is a list of specific teaching strategies which educators can utilize when addressing the unique needs of special needs students. It is very important to note that many of these teaching strategies should be used for all students.

Instructing Students Who Are Mentally Impaired

- Involve as many different senses as possible in the learning process.
- Use concrete (specific) terms rather than abstract terms. If necessary, have the student repeat the necessary information to you.
- When giving written directions, use lists instead of paragraphs. With regard to the student who can barely read, contact the remedial reading staff and arrange for reading instruction. This instruction should focus on required reading for your course and that which is vital for employment.
- Teach by demonstration (whenever possible). Don't hesitate to use hand-over-hand assistance in demonstrating how to use a tool or machine.
- Allow time to practice machine or tool processes.
- Break down complex operations into smaller tasks.
- With regard to feedback, let the learner know what is wanted, and whether or not the student is achieving it. Give lots of positive reinforcement and encouragement. Nonverbal feedback is also helpful (e.g., touching the student or task, pointing, blocking or stopping an error as it is developing, and guiding the learner's movements). In addition, provide specific feedback with regard to the student's work. For example, the educator should say, "This piece was cut exactly to the right size," or "You put these two parts together correctly," or "Try another way."

- Build the student's confidence by (a) using activities that will assure success, (b) assigning special tasks that will communicate with the educator's confidence in the student, (c) giving students an opportunity to correct their work and hand in a good project or assignment, and (d) displaying the student's good work.
- In helping students with their ability to make correct discriminations, use the "match to sample" technique in which the student is provided an example and a number of choices. The student will choose the correct alternative based upon the characteristics of the sample.
- With regard to helping the student make correct discriminations when there are **minimal** differences between the stimuli, it may be necessary to (a) present the choices in an easy form at first, (b) exaggerate attributes, (c) make the choices gradually harder, or (d) add and then fade out color cue, add and then gradually remove large cue differences, or combine these two approaches.
- Retention/memory can be improved by (a) being systematic and presenting one new piece of learning at a time, (b) relating new material to familiar material, and keeping it practical and concrete, and (c) using training techniques such as the total task method, chaining, modeling/demonstrating, and the structured overview.
- "Generalizing," or having the student apply what has been learned to the contexts, can be improved by (a) using examples from different relevant contexts and (b) practicing in settings similar to or exactly like those that will be encountered on the job.

Instructing Students Who Are Hearing-Impaired

- In private, discuss with the student his/her ability to communicate with you (lip/speech reading, use of hearing aid, writing, signing, and total communication). An open discussion with the student, which demonstrates your concern as an educator, is an excellent beginning in building rapport.
- Body language communicates messages too. Remember to not give mixed messages with your body language. Also, be alert to the body message the student is giving you (e.g., Is he/she communicating tension, nervousness, avoidance, or confusion?).
- If you will be working with an interpreter, do not instruct the deaf student as if he/she were a third party. Speak directly to the student. Also, remember that the interpreter is ethically bound to interpret everything you say. Therefore, sensitive issues or other issues concerning the student are best addressed in a meeting with that student before or after class. If you are using media where the room must be darkened, focus a small lamp on the interpreter.
- Maintain good eye contact with the student while speaking.
- Speak slowly and clearly, pronouncing each word, but without exaggerating or over pronouncing.
- Do not stand in front of a window while speaking. The light should be shining on *your* face and not the student's.
- Try to rephrase a thought rather than saying the same words over again.
- Encourage the student to read ahead on class material.
- Try to keep the noise level down as much as possible in the class/laboratory.
- Use handouts, the chalkboard, and other media.
- Install a light to indicate when dangerous machinery is on.

Instructing Students Who Are Speech-Impaired

- Always maintain eye contact and nod your head while the student is talking. This will help the student build confidence.
- Work cooperatively with speech therapist and/or communication specialist to determine which technique will help most in assisting these students to communicate more effectively.

- Encourage peer tutoring and small group activities to help the speech-impaired student develop interpersonal relationships with the other students.
- Always allow sufficient time for the student to complete his/her sentence.
- Try not to act uncomfortable (e.g., discontinuing eye contact, shifting your position, clearing your throat) when these individuals are communicating with you. Your discomfort can be very discouraging to the student.
- Do not require these individuals to present oral reports until they feel comfortable in the classroom environment.
- Model correct sentence structure for the speech-impaired student so he/she can follow your example.
- Develop a list of technical terms used in your class and share these terms with the speech specialist to help the student become more confident in pronouncing terms used in class.

Instructing Students Who Are Visually Impaired

- Orient the student to the classroom or laboratory before the course begins. Consistency and orderliness in the physical environment is very important to the visually-impaired student.
- Arrange seating so the blind student will be able to hear the instruction and to allow for the best distance and lighting conditions for the partially sighted student.
- Provide as many opportunities as possible for the visually-impaired student to observe closely or to touch the materials.
- Give materials and handouts to the student ahead of time. Also, a student peer can assist the visually-impaired student by making a carbon copy or a photocopy of his/her notes. Also, when possible, the educator can make a copy of his/her teaching notes. In this way, the visually-impaired student can review the materials with a tutor or have them transcribed into braille or taped.
- It is important to gain and maintain the student's attention. Approval or disapproval will need to be verbalized.
- Remember, there is no need to talk louder to a visually-impaired student.
- Rehabilitation counselors or special needs teachers can be useful resources in helping students use commercial or modified learning aids or tools.
- Tests may need to be prepared in large print, braille, on cassette tapes, or converted into exercises using the sense of touch. Also, it may be necessary to allow the student extra time to complete the test.
- The tape recorder is the most frequently used technique for notetaking and preparing modified learning materials for the visually-impaired student.
- The following specially designed machines are now available for the visually-impaired student: (a) OPTACON (Optical to Tactile Converter) allows students to read printed material; (b) STEREO-TONER is similar to the OPTACON but converts the printed word into a tone pattern; (c) OPTOPHONE and VISOTACTOR convert print into sound; and (d) KURZWEIL READING MACHINE converts standard English text on a computer into easily comprehended speech.
- A number of general tools or aids which can assist the student in reading or writing lessons for vocational courses include (a) braille, (b) large print, (c) tape recorders, (d) talking books, (e) raised letters, (f) slate and stylus (used to make notes), (g) braille writer (a 6-key, manually operated machine), (h) typewriters, (i) braille verifier (types braille and regular copy simultaneously), and (j) signature guides.
- Aids for mathematics and computer programming courses include (a) abacus designed for the blind, (b) raised clock faces, (c) wire geometrical forms, (d) braille rulers, (e) raised-line checkbooks, (f) raised-line boards, (g) braille dominoes, (h) braille flash cards, (i) cubes with raised braille dots used for simple mathematical problems, (j) raised-line paper

or graphs, (k) computer terminals that use braille printers, or those that type braille and conventional type simultaneously, and (l) talking calculators.

- Aids used frequently in other vocational courses include (a) braille maps, charts, and diagrams, (b) self-threading needles, (c) wooden or cardboard models of specimens that other students see through microscopes, (d) braille micrometers and other shop tools that have special raised markings, (e) braille demo tapes to mark lab equipment and models, (f) light probes with audible sounds that check the operating status of machines, and (g) guides or templates to help students align objects properly.

Instructing Students Who Are Seriously Emotionally Disturbed

- Consult with the student's parents, special education teacher, or counselor to determine whether any particular teaching techniques will help or hinder learning.
- Try to understand the student. Disturbing behaviors are the outward sign of inner turmoil.
- Go easy on bad days and avoid direct confrontations that would aggravate the situation.
- Communicate acceptance to the student and a willingness to help him or her succeed in class.
- Provide immediate feedback and reinforcement.
- Establishing a rapport and trust with the student is important.
- In the beginning of the semester, help the student gain confidence by giving him or her lessons in which success can be achieved in a series of small steps.
- A measure of privacy when the student attempts a new task can ease his or her embarrassment at any awkwardness or ineptness.
- Allow the student to correct mistakes prior to turning in an assignment or project to ease any pressure.
- Help the student to not overreact to failure and praise him or her for continuing to try.
- Cue appropriate behavior in a quiet, unemotional manner.
- In resolving discipline problems: (a) do so in privacy; (b) focus on objective facts in a calm, supportive tone; (c) actively listen to the student; (d) after listening to the student, reflect on what has been said by repeating back to the student what you've heard; (e) ask the student if he or she has any ideas about solving the problem (encourage the student to be specific); and (f) conclude with a clear understanding of the changes, time-frame, and benefits which are expected.
- In handling aggressive behavior: (a) try to remain calm and model the controlled behavior which you desire; (b) intervene by either separating the individuals involved and having them work on another activity or having them take a time-out in separate corners of the room; (c) if necessary, send an uninvolved student to the office to get help—someone who will either talk to the students or manage the class while the teacher talks to them; and (d) return to normal classroom procedure as quickly as possible.
- Access professional colleagues in special education evaluation, counseling, or therapy when the student's behavior appears to be in need of additional attention.

Instructing Students Who Are Orthopedically Impaired

- In general, students with physical handicaps will be intellectually capable and able to participate in vocational programs.
- Make the necessary modifications in classrooms, laboratories, equipment, building accessibility, and lavatories.
- For notetaking, the student can (a) use a tape recorder, (b) have a classmate slip a carbon copy into his/her notebook to duplicate notes, and/or (c) have the instructor prepare an outline of the lecture.

- For exams, the instructor can (a) give oral exams, (b) have the student dictate answers into a tape recorder or to another student, or (c) use a typewriter/computer if the student is able to type/keyboard.
- Give the student more time to complete homework assignments. Also, giving the student advance notification of assignments is helpful.
- In the laboratory, pair the student with one or more capable students in the class.
- Enlarged copies of frequently used charts and diagrams posted near the student's desk eliminates the necessity of paging through a book.

Instructing Students Who Are Other Health-Impaired

- Allow the student sufficient time for rest.
- Seat the student in the most convenient place for easy access to necessary facilities (hall, lavatory, chalkboard, laboratory work stations).
- Allow the students to work on program requirements at their own pace.
- Tape lectures so students can listen to them at home.
- Work cooperatively with the health team in order to learn more about the student's special needs.
- Use community resource personnel (social workers and itinerant teachers for home-bound students) for delivery of materials, assignments, and handouts.

Instructing Students Who Have Specific Learning Disabilities

- Use visuals and demonstrations as often as possible.
- Use concrete examples whenever possible.
- Provide student with an outline of what will be covered in class.
- Make sure all printed materials are clear and readable.
- If the student has a visual perception problem, allow him or her to tape-record assignments.
- Allow students to take tests orally or in a mode that complements their performance.
- Present new information in small amounts.
- Make sure that writing assignments are relevant to the content of the program.
- Allow students a longer period of time to complete assignments, if necessary.
- List assignments in steps.
- Task analysis can be used to lower the frustration level of these learners.
- Programmed instruction materials can be very effective with these learners.

Instructing Students with Limited English Proficiency (LEP)

- Recognize the student's cultural background and allow for the student's individual differences.
- Encourage these students to bring dictionaries to class. But remember, they may have trouble with multiple definitions.
- Provide students with copies of "terms to know."
- Use demonstrations and hands-on experience as much as possible.
- Speak slowly and use simple vocabulary and grammar.
- Use bright felt-tip markers to mark important words, passages, or illustrations.
- If possible, use a translator for important concepts.
- Work closely with LEP support personnel.
- Keep homework assignments short.
- Check for comprehension by asking the student what you have said.
- Use simple sentences when writing test items so the student can concentrate on answering the question rather than deciphering it.

Instructing Disadvantaged Students

Regarding the disadvantaged population, these individuals typically dislike school, lack motivation, and have a low self-concept or esteem. Therefore, an educator's personal commitment and high expectations for the student may be two of the biggest single factors which will make a positive difference in this individual's life. Additionally, an educator's good example (i.e., being patient, understanding, well organized, and a good manager) can be extremely valuable in motivating and positively shaping the student's behavior. Vocational education can offer a great deal to the disadvantaged student in terms of teaching academic and social skills relative to the student's potential employment. The following are additional techniques or teaching strategies that can be very useful when working with disadvantaged students.

- The educator should seek to understand the student's educational and social background through (a) assessment information, (b) interaction with former teachers, (c) discussions with counselors, and (d) visits with parents to ascertain the student's social limitations and home situation.
- Reinforce basic math, communication, and social skills. Math skills can be reinforced through hands-on learning activities. Communication skills can be improved by tactfully correcting poor grammar, when appropriate, and by providing resources that encourage reading in job-related interests. Reinforce social skills such as getting along with people, grooming, proper dress, and respect for property and authority on a continual basis.
- Continually stress the importance of finishing school. Relate the acquisition of job skills to earning an income.
- Reinforce the student's feelings of self-worth by having high expectations for the student and by providing immediate reinforcement for work well done.
- Simulate realistic job situations. All classroom and laboratory experiences should relate to employment in the occupation being studied.
- Disadvantaged students (as all students) will typically react to the learning environment in a responsible and mature manner when they are treated with respect and as adults by the educator.
- Classroom organization and discipline (being firm, but not overbearing) are especially important. Generally, disadvantaged students want and need structure and discipline within their lives. Usually, these individuals will respond to and respect teachers who are firm but sensitive.
- Help the student develop employability and job coping skills (i.e., skills associated with finding, applying for, and retaining a job).
- Help the student establish good work habits by keeping him or her involved with meaningful learning experiences. Each activity should have concrete learning objectives.
- Disadvantaged students may need more encouragement to stay on task; however, they still should be required to complete all assignments (just as they will be required to do on the job).
- Present instructions and information in clear, logical steps—building from the simple to the complex.
- Communicate technical terms clearly and concisely, and written in language the students will understand.
- Incorporate a variety of instructional methods in the curriculum (e.g., demonstrations, resource personnel, field trips, peer tutors, role playing, audiovisual aids, and on-site work experiences).
- Present supplemental material when appropriate. If such material is relevant to the acquisition of job skills, the student will not be humiliated by simplified material.
- Highlight important parts of the student's text with a light marker to prevent the student from feeling overwhelmed with a large volume of reading material.

- Progress charts can be used to motivate disadvantaged students to master new skills.
- Use flash cards (teacher-made or commercial) to reinforce new terms and the use of tools and equipment.

Generic Guidelines and Instructional Strategies

When teaching special needs students, it is very important that instructors do not limit their instructional techniques. Therefore, the following abstract of instructional techniques or strategies has been prepared which could be considered generic to all special needs populations.

- Involve as many different senses as possible.
- Use concrete terms.
- Have students repeat important information.
- Use lists rather than paragraphs for written directions.
- Teach by demonstration.
- Use hand-over-hand assistance when necessary.
- Allow practice time.
- Break complex operations into smaller tasks.
- Provide immediate feedback.
- Build confidence.

- Help students make correct discriminations.
- Help students with their retention/memory.
- Help students generalize knowledge.
- Build rapport.
- Use appropriate body language.
- Use appropriate techniques when working with an interpreter.
- Maintain good eye contact.
- Speak slowly and clearly.
- Rephrase thoughts when necessary.
- Encourage the student to read ahead.
- Keep the noise level down.
- Use various forms of media.
- Use lights to indicate when dangerous machinery is on.
- Work cooperatively with therapists.
- Encourage peer tutoring.
- Try to not act uncomfortable around special needs students.
- Help students feel comfortable.
- Model correct sentence structure.
- Develop a list of technical terms for students and/or therapists.

- Orient students before the course begins.
- Provide handouts ahead of time.
- Maintain students' attention.
- Use tape recorders for note taking.
- Try to understand the student.
- Communicate acceptance.
- Develop success experiences for the student.

- Use appropriate behavioral management techniques.
- Help the students with their note taking.
- Assist the students with exams.

- Pair students.
- Enlarge charts and diagrams.
- Use clear readable visuals frequently.
- Provide an outline of material which is being taught.

- Writing assignments should be relevant.
- Use task analysis when necessary.
- Allow for individual differences.
- Encourage students to bring a dictionary.
- Use felt-tip markers to highlight important parts.
- Do not make homework assignments too lengthy.
- Use simple sentences when writing test items.

- Simulate realistic job situations.
- Treat all students with respect and dignity.
- Provide structure and organization.
- Use progress charts.
- Use flash cards.

Basic Skills Remediation

It is very important to note that some students may need to acquire one or more basic education skills (i.e., mathematics, reading, writing, speaking, listening, interpersonal relations, and/or reasoning skills) to succeed in a vocational program. In addition, many employers will not hire an individual if he or she lacks these skills. Therefore, instruction in basic education skills may be necessary.

Modification of the Curriculum

Purpose of Curriculum Modification

When working with students with special needs, a learner's curriculum may need to be modified or adjusted to take into account major differences which could be found among these individuals. The term "curriculum modification" can be defined as tailoring an existing curriculum to the unique needs of students as they pursue an occupational goal. However, it should be strongly emphasized that modifying a curriculum **does not** mean that an educator should lower or alter the standards of his or her program. What it **does** mean is that the Admission Review and Dismissal (ARD) Committee (for handicapped students) or coordinated planning team (for disadvantaged and LEP students) determines which essential elements in the regular school curriculum would be appropriate for a student's needs. The *State Board of Education Rules for Curriculum* offers the following key points (Texas Education Agency, 1985).

1. For students with special needs, school districts shall provide modifications in methodologies, pacing, and materials to ensure that instruction is delivered, as appropriate, in the essential elements.
2. Students with special needs shall be instructed in those same essential elements in a manner appropriate to their needs.
3. School districts shall implement the provisions (under Chapter 75) in a manner which will enable all students to participate actively in a well-balanced curriculum and master, to the best of their abilities, the knowledge, skills, and competencies established through the essential elements.
4. Specialized personnel and regular program personnel shall be jointly responsible for the cooperative delivery of effective instruction in the essential elements, as appropriate.

Responsibilities of the Vocational Educator

The primary responsibility of the vocational educator in the curriculum modification process is to help the special needs student establish and reach realistic occupational goals. In an effort to accomplish this, the vocational educator must identify:

1. pertinent information about what will be taught in a vocational program;
2. necessary requirements for program completion;
3. multiple exit points (jobs that the learner can prepare for in a vocational program); and
4. entry-level competencies expected by employers for each of the exit points.

It is also the responsibility of every vocational educator to establish an effective and wholesome learning environment for their students. Providing this environment may involve modifying the vocational facility, equipment, tools, and/or instruction. This information is provided in the following section.

Modification of the Learning Environment

The term *learning environment* refers to both the **physical** and **instructional** setting of the vocational classroom/laboratory. It is the responsibility of each vocational educator to work at developing a learning environment which will contribute to the overall well-being and success of every student. The key factors found in a wholesome learning environment are those which promote:

1. **Safety, organization, and physical comfort.** In the vocational laboratory, it is absolutely crucial that each student abide by safety rules set by the instructor. In addition, the laboratory should be kept well organized and clean. A laboratory which is safe, well organized, and physically comfortable helps promote high morale and good work habits.
2. **Respect and acceptance.** Within an effective learning environment, students will show respect not only for the instructor but for each other as well. The instructor should be the student's best role model. The care and acceptance given by the instructor to each student (disabled or nondisabled) will go a long way in promoting peer acceptance, a positive attitude, and healthy self-esteems.
3. **Discipline.** A wholesome learning environment is one which promotes discipline and a positive self-concept within each student. Inappropriate behavior has the potential to seriously affect classroom safety, morale, and the overall learning process. Ways in which the instructor can help the student modify inappropriate behavior include (a) using the time-out technique, (b) developing student-teacher contracts, (c) ignoring negative behavior—whenever possible, and (d) rewarding appropriate behavior with approval and praise.
4. **Flexibility.** An effective learning environment is flexible and can adapt to a special student's unique needs (e.g., slower rate of learning, inability to access regular tools/equipment, or remedial needs in reading or math). A flexible environment fosters individualized programs through which a special learner can develop marketable skills for employment.

For information on modifying facilities, equipment, and tools for a vocational classroom, refer to the *Vocational Special Needs Teacher Training Curriculum*, available through the Extension Instruction and Materials Center.

Answers
to
Exercises

Exercise A-1

How to Use This Manual

1. How does your interest in this manual and that of the author compare?
   Both want the learning process to be easy as possible.

2. List the four parts of each assignment that are designed to make learning easy.
   (1) the learning objectives
   (2) the technical information
   (3) the exercise
   (4) the test

3. What makes the objectives important?
   The objectives tell you what you should be able to remember after completing this assignment.

4. Of what secondary importance are the objectives?
   The objectives give a clue as to the subject matter of the test.

5. Give the proper sequence or order of study so that you can learn the most from an assignment.
   First read the objectives, then read the technical information, and then answer the exercise questions.

6. What is the purpose of studying the assignment in the proper sequence?
   Studying in the proper sequence guides you over the same information three times.

7. Why is the kind of paper you use and the way you answer questions of importance?
   How you keep your notebook is important since your notebook should show anyone what you have studied while in the program.

8. If your teacher-coordinator is not particularly interested in how many assignments you turn in, about what is he or she concerned?
   His or her main concern is how much you have learned.

9. Why should the test be a snap?
   If you study the assignment as directed, you will have covered the information on the test three times before taking the test, which is based on information given in the objectives.

10. Explain how the success or failure of the author depends on how well you do.
    If you fail to learn, the author, through his manual, has failed to teach.

Exercise A-2

Occupational Outlook

1. On which characteristics does the ability to quickly diagnose mechanical problems depend?
good reasoning ability and a thorough knowledge of automobiles

2. Name five examples of areas in which automotive technicians may specialize.
(1) *automatic transmission specialist*, (2) *tune-up specialist*, (3) *automotive air-conditioning specialist*, (4) *front end specialist*, (5) *brake specialist*

3. Where is most of an automotive technician's work done?
indoors

4. What are some of the negative aspects of being an automotive technician?
Technicians frequently work with dirty and greasy parts, and in awkward positions. They often must lift heavy parts and tools. Minor cuts, burns, and bruises are common.

5. How many people were employed as automotive technicians in 1988?
748,000

6. For whom did technicians primarily work?
automotive dealers, automotive repair shops, gasoline service stations, and automotive service facilities such as department, automotive, and home supply stores

7. What percentage of automotive technicians are self-employed?
20 percent

8. How do most automotive technicians learn the trade?
by assisting and working with experienced technicians

9. Why is it increasingly more difficult to learn the automotive trade by working with experienced technicians?
because automotive technology is rapidly increasing in sophistication, and most training authorities recommend that persons seeking automotive trainee jobs complete a formal training program

10. Why is it becoming more important for a technician to understand electronics?
because electronics are being used in a growing variety of automotive components

11. List some of the components in which electronics are being used other than engine controls and dashboard instruments.
brakes, transmissions, steering systems

12. Why are technicians becoming more involved in diagnosing electronic malfunctions?
Electronics are becoming so commonplace that most automotive technicians must be familiar with at least the basic principles of electronics in order to recognize when an electronic malfunction may be responsible for a problem, and to be able to test and replace electronic components.

13. What qualities do employers look for in people looking for trainee technician jobs?
people with good reading and basic mathematics skills who can study technical manuals to keep abreast of new technology and learn new service and repair procedures and specifications

14. What background do many employers regard as the best preparation for trainee positions?
completion of a vocational training program in automobile mechanics, either in high school or at a postsecondary institution

15. Who usually furnishes hand tools for technicians?
the technician

16. Who usually furnishes power tools, engine analyzers, and other test equipment?
employers

17. What kind of advanced training may an employer furnish for a technician?
training at factory training centers in special areas such as electronic fuel injection or air conditioners

18. For which automotive technicians are job opportunities expected to be plentiful?
those who complete training programs in high school, vocational and technical school, or community colleges

19. How does the increase in employment of automotive technicians through the year 2000 compare to the average for all occupations?
Employment of automotive technicians is expected to increase more slowly.

Exercise A-3

Owning Your Own Business

1. What kind of community should you look for when trying to locate a new business?
   a growing and dynamic community

2. Why should you not locate your shop in an area in which many vacant buildings exist?
   People tend to avoid doing business in areas where there are many vacant buildings.

3. Why should you not locate your shop close to other automotive repair shops?
   You do not want to share your customers with other shops.

4. Why is it sometimes an advantage to purchase an existing shop rather than start a new shop?
   People who have used a shop for some time tend to want to stay with the shop when ownership changes.

5. Why is it important to check the volume of an existing business before you purchase it?
   The place could be losing money due to subtle economic changes in the community.

6. Why is customer appeal important?
   When competitive shops are equal, customers will use the one that has more appeal.

7. Why should you get an attorney's advice before signing a contract to rent a building?
   There may be hidden clauses in the contract.

8. What is equity capital?
   your own money

9. Your savings consist of which items?
   your savings account, life insurance policies, land, buildings, livestock, and valuable collections of all kinds

10. What is the advantage of borrowing from an insurance policy?
    The money can be kept and used as long as necessary.

11. Why are canceled checks important?
    The canceled checks become proof of payment and are absolutely necessary for income tax purposes.

12. What is the most common type of business organization in the United States?
sole proprietorship

13. List six advantages of *sole proprietorship.*
    - *(1) It is easiest to go in to since it is the simplest form of organization.*
    - *(2) Lawyer fees are less than the other types of organization.*
    - *(3) Fees for licenses are lower.*
    - *(4) There is far less government red tape.*
    - *(5) The owner is the boss and decision maker.*
    - *(6) Business profits are not shared with others.*

14. What are the advantages of a partnership?
There is a bigger pool of ideas, skills, knowledge, and energy.

15. What is the financial responsibility of each partner in a partnership with regard to the actions of a single partner?
They are all collectively (as a group) responsible for the debts of the business.

16. What should be spelled out in a partnership agreement?
the duties and responsibilities of each member and methods and procedures for running the business

17. Why is it absolutely necessary to have a reliable accounting system in your business?
Without this information, you can be in financial ruin without knowing about it until it is too late to do anything about it.

18. Why is the employee identification number important?
This number is used on forms submitted with social security and federal income taxes that have been withheld from employees' salaries.

19. What is the significance of the state business identification number?
This number is used on forms to submit sales taxes as well as state unemployment taxes, state income taxes, and such other forms as required by the state.

20. List four kinds of insurance essential for your shop.
    - *(1) fire insurance*
    - *(2) liability insurance*
    - *(3) automobile insurance*
    - *(4) workers' compensation insurance*

21. Under which policy is legal fire insurance usually found?
liability insurance coverage

22. What are the four requirements under the law behind workers' compensation?
That an employer—
    - *(1) provide the employee with a safe place to work;*

(2) hire competent co-workers;
(3) provide safe tools; and
(4) warn employees of an existing danger.

23. List two types of desirable insurance.
(1) business interruption insurance
(2) burglary or robbery insurance

24. Which item is the most expensive cost of operating a business?
salaries paid to employees

25. What is the best way of defining job responsibilities?
by writing a job description

26. What are two common pitfalls shop owners make when hiring personnel?
(1) hiring overqualified people who will not stay long
(2) hiring someone who cannot do the work

27. How should you begin every lesson in on-the-job training?
Demonstrate the procedure slowly, making sure the trainee understands each step and the reason for it. Discuss what you are doing, and encourage questions.

28. Explain the demonstration procedure.
Begin every lesson by explaining what you are going to teach.

29. On what basis are most automotive technicians paid?
strictly on the commission basis

30. What is an advantage of being paid on commission?
It develops an incentive to work.

31. What are *fringe benefits?*
benefits, services, or goods received in addition to the normal wages or salary

Exercise B-1

Shop Safety

1. What is one of the primary causes of accidents?
   a careless attitude toward safety practices

2. How should horseplay be dealt with by the management of the shop?
   Horseplay should never be permitted, even in its most innocent form.

3. Which muscles are used to lift heavy loads correctly?
   leg muscles

4. In what position should the load be carried when moving a load with a crane or lift?
   as close to the floor as possible

5. Name three safety features of grinders.
   (1) guards
   (2) tool rests
   (3) shields

6. Why should open flames near a battery be avoided?
   Gases formed during charging are explosive.

7. What should be done if acid is spilled on the skin?
   The skin should be washed with water and neutralized with bicarbonate of soda.

8. What type of accident can result from disorderly and cluttered shops?
   falls

9. When should test equipment be connected and disconnected to subassemblies of an engine?
   when the engine is not running

10. Why should loose clothing not be worn in the shop?
    It may get caught in the machinery.

11. Why should micrometers, calipers, and other precision instruments not be stored with other tools?
    They are easily damaged, and no measurement is better than an incorrect one.

12. If they are not double-insulated, with what should electrically powered tools be equipped?
    a three-wire connector

13. Why should calipers and dividers not be carried in pockets?
The points may puncture the skin.

14. How should an automobile that has had its wheels removed be supported?
It should be supported by jack stands.

Exercise B-2

Hand Tools

1. What are three basic rules regarding the purchase, care, and use of hand tools?
   (1) Purchase only quality tools.
   (2) Keep the tools in good condition.
   (3) Use the right tool for the right job.

2. How are common screwdrivers for slotted screws classified?
   Common screwdrivers for slotted screws are classified by size according to the combined length of the shank and blade.

3. Why should the blade of a screwdriver fit the screw slot it is used on?
   This prevents the screw slot from becoming burred and the blade tip from being damaged. At the same time, it reduces the force required to keep the screwdriver in the slot.

4. Describe the tip of a Phillips-type screwdriver.
   an X-shaped, fluted tip

5. Where are offset screwdrivers used?
   where there is not enough clearance to use a standard screwdriver

6. For what kind of work are ball-peen hammers designed?
   driving and forming metals

7. For what jobs are soft hammers and mallets used?
   to pound or drive objects or perform other operations where a steel hammer would mar or perhaps break the work

8. What will be the relative position of the hammer to the object it strikes at the instant contact is made if the hammer is held correctly?
   The face of the hammer and the object being hit will be parallel.

9. What is the purpose of the slip joint in combination-joint pliers?
   The slip joint permits the jaws to be opened to a wider position for gripping larger diameters.

10. For what jobs are diagonal pliers used?
    to cut and strip insulation wire, cut cotter pins to the proper length, spread cotter pins, and cut off wire close to terminals

11. For what are long-nose pliers chiefly used?
    in ignition and carburetor repair work

12. What is an advantage of thin jaws on water-pump pliers?
Thin jaws permit their use in confined places.

13. What is the only purpose for which battery pliers are used?
for loosening and tightening the nuts on battery terminal lugs

14. In what respect are battery pliers and ignition pliers unique among pliers?
Ignition pliers and battery pliers are the only kinds designed primarily for turning nuts that are difficult to turn with wrenches.

15. How did the open-end wrench get its name?
because it has an opening consisting of two parallel jaws that fit over the nut or bolt head

16. Why is the head of an open-end wrench cast at a 30° offset from the handle?
This angle allows the wrench to be used in a restricted area of 30°.

17. Most manufacturers make the lengths of wrenches about twelve times the opening size. What are the two reasons for this proportion?
    (1) This proportion allows greater leverage, since the larger the nut, the harder it is to turn and the more leverage needed.
    (2) Also, it prevents technicians from stripping the threads or breaking a small size bolt or screw by applying too much force with a wrench of the wrong proportions.

18. Why are box-end wrenches better for breaking a nut loose or tightening a nut than an open-end wrench?
They engage the nut more securely than an open-end wrench.

19. Why is the head of a box-end wrench set at a 15° angle?
When a box-end wrench is used on a nut that is on a flat surface, the handle cannot be cocked enough to allow room for the fingers. Thus, the handle is set at an angle.

20. What features make the socket wrench the easiest and fastest type of wrench to use?
It has the best features of both open-end and box-end wrenches with the additional feature of being adaptable for use with a wide assortment of handles.

21. How many points do socket wrenches for hexagon nuts have?
six or twelve points inside one end

22. How many points do socket wrenches for square nuts have?
four or eight points inside one end

23. Why is the twelve-point socket most popular for hexagon nuts?
because it can be used to limit the swing to 30°

24. Name two advantages of using the ratchet handle with sockets.
   (1) *Nuts may be tightened or loosened without removing the handle.*
   (2) *It may be used in close quarters where the angle of swing is even less than 30°.*

25. For what purpose is a torque handle used?
   It is used to regulate the amount of force applied to the nut.

26. What are the two methods of applying the correct torque to a nut using a torque wrench?
   (1) *One method is to use a gauge on the handle that registers the amount of torque exerted.*
   (2) *The other method uses a torque-release mechanism in the handle to release the torque on the socket when a preset torque limit is reached.*

27. With which fasteners are spanner wrenches used?
   special round nuts

28. For what job is the Crescent wrench particularly useful?
   turning odd-sized nuts and bolts

29. In what sizes are Crescent wrenches made?
   from 2 to 24 inches

Exercise B-3

Measuring Tools

1. Name the parts between which measurements are taken on a micrometer.
the anvil and the face of the spindle

2. Which part is used to adjust the micrometer to the thickness of the part being measured?
the spindle

3. What is the purpose of the graduations on the thimble?
for recording the fractions of turns of the thimble

4. What is the purpose of the graduations on the index line?
to record the number of complete turns made by the thimble

5. What is the distance between the graduations on the index line?
0.025 (1/40) inch

6. What is the distance between the divisions on the thimble?
0.001 (1/1,000) inch

7. What is the smallest measurement permitted by the vernier scale?
0.0001 (1/10,000) inch

8. How is the reading to 1/10,000 inch taken?
by determining which line on the vernier scale lines up with any line on the thimble

9. Within what distance do the limits of all micrometers fall?
1 inch

10. What is the largest size of micrometer?
23 to 24 inches

11. Explain how to hold a small micrometer properly.
Small micrometers are held in the palm of the right hand with the knurled portion of the thimble between the thumb and forefinger. The frame is held with either the little finger or the ring finger of the right hand or both fingers pressing it against the heel of the hand.

12. What are the results of clamping the work too tightly?
inaccurate reading and damage to the micrometer

13. What step should be taken to ensure that the full diameter of a round work is between the faces?
The spindle should be rocked slightly over the curved surface while the adjustment is being made.

14. How are micrometers held when miking objects that are too large or too heavy to hold?
A large-size micrometer is held in both hands. The left hand supports the anvil against the work. The right hand manipulates the thimble.

15. Why are the contact points of inside micrometers slightly rounded?
to permit accurate contact with either parallel surfaces or inside curved surfaces

16. What are the three types of scales used on depth gauges?
(1) the 64th-inch scale
(2) the vernier scale
(3) the micrometer

17. For what purpose are calipers actually designed?
transferring measurements from measuring tools to the work or from the work to measuring tools

18. Of which parts does a telescoping gauge consist?
a head and a handle set at right angles to it

19. How is a telescoping gauge held in place after the measurement has been taken?
The locking screw is then tightened, holding the plunger at the setting.

20. For what purpose are bent-wire feeler gauges used?
to check the spark plug gap and the voltage regulator cutout gap in thousandths of an inch

21. For what purpose are bent-blade feeler gauges used?
to set the gap between the points in the distributor and regulator and to set the spark plug gap

22. How is a wider range of thicknesses obtained than those available in the feeler gauge blades?
by combining two or more blades

Exercise B-4

Power Tools and Equipment

1. Name the three categories of power tools used by automotive technicians.
   (1) pneumatic
   (2) electric
   (3) hydraulic

2. Why is it important that you know how to properly use power tools?
   because the very power that makes these tools useful and laborsaving also makes them dangerous

3. What is one of the first precautions to be taken with any power tool?
   Read the operating instructions supplied by the manufacturer.

4. What should you do before using a tool with which you are unfamiliar?
   Ask for a demonstration of the proper use of it.

5. What are the advantages of using air tools rather than electric tools?
   They are lighter and more compact. They eliminate the dangers of electric-powered tools.

6. What type of maintenance is required of pneumatic tools?
   It is vital they be lubricated before use.

7. What are the two types of air or impact wrenches?
   (1) pistol-grip and (2) butterfly

8. Impact wrenches are made with what sized drives?
   3/8, 1/2, and 3/4 inch

9. What should an inexperienced technician try to avoid while learning to use an impact wrench?
   overtightening or leaving the nut or bolt loose

10. What distinguishes an impact socket from a regular socket?
    It is usually flat black, and a regular socket is usually chrome.

11. What usually prevents the cutter on an air chisel from flying off when the air is turned on?
    a steel retainer spring

12. What should be done to prevent the cutter from flying off if the air chisel has no steel retainer spring?
    Press the cutter against the work piece when using the air chisel.

13. What kind of personal protection equipment should be used when cleaning parts with an air gun?
eye protection

14. Why should parts containing asbestos never be air-blown?
Asbestos can cause cancer.

15. What characteristics makes the air drill an excellent tool for many types of repair jobs?
its speed adjustment capabilities and power output

16. List four different types of jobs an air drill can perform.
(1) drill holes, (2) grind, (3) polish, and (4) clean parts

17. What failures should you guard against when using an air drill?
broken drill bits, grinding stones, and steel bristles from the rotary brush

18. What kind of drill jobs are performed on drill presses?
work which can be brought to the drill press

19. What kind of drill is used in electric drills?
twist drills

20. What kind of material is used to make drills for electric drills?
carbon or high-speed steel

21. What kind of jobs are performed on pedestal grinders?
sharpen tools, touch up small parts, and burr them

22. What kind of jobs are performed on grinders with steel wire brushes?
buff parts and clean them

23. Where should a floor jack be placed in order to prevent damage to a vehicle when lifting it?
under a solid part of the car, usually the the axle or frame

24. What should support a vehicle once it has been raised by a floor jack?
jack stands

Exercise C-1

Fundamentals of Electricity

1. What is voltage?
Voltage is simply the pressure on electrons.

2. What is an amp?
One ampere of current is one coulomb of electrons passing a point in one second.

3. What is an ohm?
The opposition to the flow of current is called resistance. The unit of measurement for resistance is the ohm.

4. What are the three formulas for Ohm's law?
(1) $E = IR$ (2) $I = \frac{E}{R}$ (3) $R = \frac{E}{I}$

5. A 12V car battery is connected to a light with 25Ω of resistance. How much current is passing through the light?
0.48A

6. Which metal has the best conductivity?
silver

7. How much current will normally flow through an insulator before the voltage reaches breakdown?
No current will flow through an insulator.

8. In figure 18, if the voltage source is 15V and the resistance is 3Ω, what is the current in the circuit?
5A

9. Assume that the circuit current in figure 18 is 2A and the voltage is 7V. What is the resistance?
3.5Ω

10. A technician wants to replace the two headlights, which take 3A, with a resistor. The technician wants to use the resistor instead of the lamps to avoid the heat and light generated when testing a 12-volt battery. What size resistor should the technician use?
4Ω

11. If figure 18 has a resistance of 4 ohms and circuit current of 2A, what is the voltage?
8V

Exercise C-2

Circuit Analysis

1. When measuring the resistance of a resistor in the circuit, what should you do about the voltage source?
When measuring resistance, any voltage in the circuit will change the meter reading. The meter places a small voltage across the portion of the circuit to be measured and tests for the current. Any additional voltage would change the appropriate current level. Therefore, all of the voltage must be removed from the circuit before testing.

2. If a DVOM with an accuracy specification of (2.0% + 2d) shows a reading of 20.4V, what is the range of possible true voltages?
19.8 to 21.0V

3. How much current in μA will there be if the circuit has 1.2kV and 24MΩ?
50μA

4. Insert a 150Ω resistor in the place marked "AMP" in figure 7, and find the voltage drop across this 150Ω resistor.
1.27V or rounded to 1.3V

5. If R_1 burned out leaving an open, in figure 7, what would be the voltage drop across the 150Ω resistor from question 4?
1.17V or rounded to 1.2V

6. In figure 7, if a short developed across R_2, what would be the voltage drop across the 150Ω resistor from question 4?
9V

7. In figure 7, if a short were placed in the space marked "AMP," how much current would pass through R_2?
9mA

8. In figure 7, if the voltage source is changed to 12V and a 1.2kΩ resistor is placed in the spot marked "AMP," what would the total circuit current be?
rounded to 5.7mA

C-2 Circuit Analysis

Laboratory Experiment

Essential Elements: (gg)(1-3)

Objectives

This lab will be used to test your computations and determine if your math is correct when you analyze a circuit. You will start by analyzing each circuit, record all of your results, then build the circuit, and measure it. When you compare the calculated results with the measured results, you will be able to confirm the accuracy of your calculations.

Equipment

1	battery holder for four dry cell batteries
4	dry cell batteries
1	package of 10 jumper leads with alligator clips
1	DVOM
1	470Ω 5% resistor (Colors Yellow, Violet, Brown, and Gold)
1	1000Ω 5% resistor (Colors Brown, Black, Red, and Gold)
1	2.2kΩ 5% resistor (Colors Red, Red, Red, and Gold)
1	4.7kΩ 5 % resistor (Colors Yellow, Violet, Red, and Gold)

Procedures

The four dry cell batteries in this lab will provide 6V. If this arrangement providing 6V is not available or the resistors that you have chosen are not available, use components that are as close as possible, and have the instructor check the accuracy of your calculations.

In figure 1 use the 6V for V_1, the 2.2kΩ for R_1, 1,000Ω for R_2, and the 470Ω for R_3.

1. Calculate the resistance for the parallel combination of R_2 and R_3. Record this value, and leave space next to it for the measured value.
   319.7Ω, rounded to 320Ω

2. Calculate the total circuit resistance, and record this value. Leave space for the measured value.
   2520Ω (rounded)

3. Calculate the total current for the circuit of figure 1, and record your answer.

2.38m rounded to 2.4mA

4. Calculate the voltage drop across each resistor, and record this voltage drop leaving space on your paper for the measured voltage drop.
   R_1 *= 5.2V rounded to 5V*
   R_2 *and* R_3 *will each have 6 volts minus the voltage drop across* R_1*.*
   This will be approximately 1V.

5. When all the calculated values are recorded, record the color code values of all the resistors. Next, use the resistance function of your digital meter to measure the resistance of the four resistors. Record these values next to the color code values.
   470Ω 5% resistor (colors Yellow, Violet, Brown, and Gold)
   1000Ω 5% resistor (colors Brown, Black, Red, and Gold)
   2.2Ω 5% resistor (colors Red, Red, Red, and Gold)
   4.7kΩ 5% resistor (colors Yellow, Violet, Red, and Gold)

   The measured values should be within 5% of the color code values.
   The 470Ω should read between 446 and 494.
   The 1000Ω should read between 950 and 1050.
   The 2.2kΩ should read between 2090 and 2310.
   The 4.7kΩ should read between 4465 and 4935.

6. Use the jumpers to connect R_2 and R_3 in parallel. Measure the combined parallel resistance, and record it next to the measured value. Recheck your calculations if there is a difference of more than 10% between the measured and calculated values.
   288 to 352Ω

7. Use an additional jumper to connect R_1 to the parallel resistors, and measure the total resistance for the circuit. Record this value, and compare it with the calculated resistance. If there is more than a 10% difference, recheck your calculations.
   2268 to 2772Ω

8. Insert the batteries into the battery holder, and use the jumpers to connect the battery pack to the resistors. Measure the voltage drop across each resistor, and record these values.

   The measured values will be lower than the calculated values if the battery voltage is lower than the 6V used for calculations. Adjust the expected measured values downward based on the battery voltage. Also, the total of the voltage measured across R_1 plus the voltage measured across R_2 or R_3 should equal the actual battery voltage.
   R_1 *= 5.2V rounded to 5V*
   R_2 *and* R_3 *will each have 6 volts minus the voltage drop across* R_1*. This will be approximately 1V.*

9. Use Ohm's law to find the total circuit current by dividing the voltage drop across R_1 by the resistance of R_1. Compare the measured values with the calculated values. The difference should not be more than 10%, provided your battery voltage is close to the 6V that you used for the calculations.

   Watch the battery voltage again. The measured current will be lower with a lower battery voltage. The current should be within 10% if the battery voltage is close.
   2.4mA or 0.0024A

   In figure 2 use the 6V for V1, the 4.7 kΩ for R_1, 2.2kΩ for R_2, and the 1,000Ω for R_3.

10. Calculate the resistance of the series combination of R_1 and R_3. Record this value, and leave space next to it for the measured value.
    5.7kΩ

11. Calculate the total circuit resistance, and record this value. Leave space for the measured value.
    1.58 or rounded to 1.6kΩ

12. Calculate the total current for the circuit in figure 2, and record your answer.
    3.78mA or rounded to 3.8mA

13. Calculate the voltage drop across each resistor, and record this voltage drop, leaving space on your paper for the measured voltage drop.
    R_2 is 6V, R_1 is 4.9V or rounded to 5V, and R_3 is 1.1V rounded to 1V.

14. Use the jumpers to connect R_1 and R_3, and measure the series resistance. Record this value, and compare it with the calculated values.
    5,415Ω to 5,985Ω

15. Connect R_2 and measure the total circuit resistance, and record and compare this value with the calculated values.
    1.4kΩ to 1.7kΩ

16. Finally, connect the battery pack to the circuit, and measure and record all voltages.

    The measured voltages should be within 10% of the following calculated voltages except for the lower battery voltage. Adjust the expected measured voltages down for lower battery voltages.
    R_2 is 6V. The voltage across R_1 plus the voltage across R_3 is 1.1V rounded to 1V. The voltage across R_1 plus the voltage across R_3 should equal the battery voltage.

17. Use the measured voltage drops across R_1 and R_2 divided by their resistances to find the current. Add these two currents for the total circuit current, and record and compare this value with the calculated values.
3.4mA to 4.2mA

Exercise C-3

Conductors and Resistors

1. Write in the resistance value for the following resistor color codes:

   a. Brown, Black, and Red
   1,000 Ω

   b. Yellow, Violet, and Brown
   470 Ω

   c. Red, Red, and Orange
   22 kΩ

   d. Red, Black, and Yellow
   200 kΩ

2. What kind of resistor will decrease its resistance when the temperature increases?
   thermistor with negative temperature coefficient

3. Which type of pot would be used to control a fan motor that draws a lot of current?
   wire-wound pot

4. What problem would be caused by splicing a copper wire to an aluminum wire?
   Galvanic corrosion will result.

5. How far should a splice be from other splices, connectors, and branches in the harness?
   1 1/2 inches

6. What wire gauge of fusible link would you use to connect with a particular wire gauge of harness wire?
   four wire gauges smaller than the wire harness

7. If the terminal in a connector is damaged and is not designed to be removed, how can you repair it without replacing the whole connector?
   Bypass the connector with a bullet connector.

C-3 Conductors and Resistors

Laboratory Experiment (for repairing wire [optional])

Objectives

In this lab, the student will practice repairing wire. Although soldering is not included in this lab, your instructor may add soldering if the equipment and facilities are available.

Equipment

3	feet of insulated wire
6	clips (the size of the clips should match the wire size)
1	roll of electrical tape
1	crimping tool (*Note:* if the crimping tool does not include a feature for cutting the wire and stripping the insulation, additional tools will be necessary.)

Procedure

1. Cut the wire into six pieces. Strip both ends of each piece of wire.

2. Use the techniques described in the lesson to crimp all six pieces of wire together to form a complete loop.

3. Tape the crimp connections.

4. Cut one of the pieces of wire in the loop, strip the insulation and use the DMM to test the resistance of the loop. There should be no significant resistance in the loop. If there is resistance, make some additional cuts in other sections to locate the faulty connection. If you find a faulty connection, examine it and determine what you did wrong to cause the resistance. By examining your error, you can avoid making the same mistake again.

Exercise C-4

Magnetism

1. If the number of turns of wire wrapped around an electromagnet is doubled, how will it affect the magnetic force?
   It will increase.

2. If the north pole of an electromagnet is brought close to an iron rod so that, when the electromagnet is energized, the iron rod jumps away, what does that indicate about the iron rod?
   The iron rod is a magnet, and the end of the iron rod that was brought close to the electromagnet is its north pole.

3. Of what material are the brushes in an electric motor made?
   carbon

4. What is the part of the electric motor that rotates called?
   armature

5. What is the device called that pulls a lever causing the doors to lock electronically?
   solenoid

6. What kind of switch is used to sense an overheated engine?
   bimetallic

7. The temperature-sensitive, time-delay switch is wired in series with the ignition switch. The switch is designed to open up after passing current to the rear defrosters for a period of time. If a person left the rear defroster switch on all the time, how many periods of current would the rear window receive during the time this person left home, went to the store and returned directly back home?
   two

8. The flasher switch has the heating element in series with the current going to the load. If the load is four light bulbs around the car and two light bulbs burn out, how does this affect the rate of heating or the length of each warm-up cycle of the flasher?
   longer

C-4 Magnetism

Laboratory Experiment

Essential Elements: (gg) (1-3)

Objective

In this lab, the students will examine the properties of electromagnets.

Equipment

1	voltage source (batteries and battery holder)
3	nails about 2 inches long
4	feet of insulated wire
1	DVOM

Procedure

A solenoid consists of a coil of wire and a plunger or core that can move inside the coil. You will start by making a solenoid.

1. Strip about 1/2 inch of insulation from both ends of a strip of wire 2 feet long. Loosely wrap this wire around one of the nails to form an electromagnet.

2. Test the electromagnet by connecting the wire to the voltage source, and try to pick up one of the other nails with the electromagnet. There should be a strong magnetic force attracting the other nails.

3. Disconnect one of the wires from the voltage source, and pull the nail about halfway out of the coil. When the wire is reconnected, the nail should pull back into the coil. This is the action of a solenoid. Pull on the nail while current is applied to the coil, and check the strength of your solenoid.

4. Use the other 2 feet of wire to make another electromagnet just like this one.

5. Connect the two electromagnets in parallel, and bring their ends together. Then switch the end of one of the electromagnets. Why do the magnets attract each other one way and repel each other when their ends are switched?

Note: Do not leave the electromagnets hooked up longer than necessary as they will quickly drain the batteries.

In step number 5, the electromagnets attract each other when the polarity of the ends that are brought together is different, and they repel each other when the polarity is the same.

Exercise C-5

Schematics (Electrical Road Maps)

1. What two plugs have to be disconnected to remove the left front door lock switch?
   C378 and C382

2. What color wire feeds the current to the front door lock motors to unlock the doors?
   TAN

3. What kind of high current protection does each motor have inside the motor housing?
   self-resetting circuit breaker

4. What kind of switch/relay is in the door lock relay assembly (single-pole, double-throw; double-pole, single-throw; single-pole, single-throw; or double-pole double-throw)?
   single-pole, double-throw

5. What part of the circuit will still work, if the 20 amp fuse (CTSY-CLK FUSE) blows?
   nothing

C-5 Schematics (Electrical Road Maps)

Workbook

Essential Elements: (gg)(1-3)

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1. For the drawing in figure 1, on a separate sheet of paper, list the items that the current will pass through from the fuse panel (hot in accy or run) to the "L" input of the wiper motor. Include the number showing the wire or wire harness, each numbered plug, the interval governor, and any numbered junctions or splits.
   red wire #63, junction C309, red wire #63, interval governor, white wire #58, wiper motor

2. In figure 1, notice the black wire with white strip, #941. If wire #941 coming from point W on the interval wiper/washer switch was shorted to wire #941 in plug C309, describe the effect on the circuit.
   No effect, the wires are joined inside the interval governor.

   The lamp out warning system shown in figure 2 uses resistance wire for a voltage drop when there is current flow. Notice where the wire shows the zigzag just like a resistor symbol. With all lamps on, the voltage drop will be around 0.5 volt. When a lamp goes out, the voltage drop goes down to 0.25 volt. The solid-state module will see this small difference in voltage and turn on a warning indicator by grounding that circuit.

3. A customer comes in and shows you that one low beam headlight is out and the indicator light is not on. You refer to figure 2 for the circuit and check the indicator by removing a tail light. The indicator does not show the loss of the tail light. What would you recommend to look at next?
   the fuse number 18 feeding the warning buzzer and the lamp out indicator or fuse number 6 feeding the module

The schematic in figure 3 shows the circuit for the illuminated entry. This circuitry will cause the inside lights to go on when the door handle is operated. There is a 20-second timer that will keep the lights on after the door handle is operated.

Examine figure 3, and notice that when the door handle is operated, it will provide the path to ground for the 20-second timer in the illuminated entry timer module. When this ground circuit is made, the relay pulls the contacts closed on terminal B. The relay closure on terminal B provides a ground for the footwell courtesy lights. When the ignition key is on, current will be supplied through fuse number 16 to the solid-state module. This will open the switch at terminal D and disable the 20-second timer.

4. In figure 3, if a short to ground happened where the white wire connects to the right footwell courtesy light, what would happen to the interior lights? *They would stay on continuously until the short was cleared.*

5. In figure 3, what would happen if fuse number 15 opened? *All the interior lights would no longer work.*

Exercise C-6

AC and Computer Signals

1. What is the frequency of a sine wave that takes 20 ms to complete 6 cycles or waves?
   300 kHz

2. What is the dc voltage equivalent of a 15-volt peak voltage when you are talking about the amount of work the voltage can do?
   10.6 V

3. If one sine wave on the screen of an oscilloscope takes 4.3 horizontal divisions and the Time/Div control is on 5 ms per division, what is the frequency of the signal?
   46.5 kHz or rounded to 47 kHz

4. Two signals on a dual trace scope each take 6.5 divisions horizontally for one wave and are 0.8 division different at the point they cross the center line. How many degrees are they out of phase?
   44.3 degrees or rounded to 44 degrees

5. What three things will influence the capacitance of a capacitor?
   (1) the size of the plates
   (2) the distance between the plates
   (3) the type of material used for the insulator or dielectric

C-6 AC and Computer Signals

Laboratory Experiment

Essential Elements: (gg) (1-3)

Objective

In this lab, the student will examine the properties of capacitors.

Equipment

1	6-volt voltage source (batteries and battery holder)
1	100 mF or higher capacitor
2	resistors; 1 kΩ and approximately 9 kΩ
1	DVOM

Procedure

The capacitor should have a voltage rating that equals the 6-volt source or greater. The electrolytic capacitors are sensitive to the polarity of the voltage they are connected across. On the side of the capacitor there will be a plus sign and a minus sign showing which lead to connect to the positive and negative part of your circuit. The voltage source should have the positive lead connected to resistor R_1, and the capacitor should have its positive lead connected to the other side of R_1. The capacitor may burst and throw pieces of material and chemicals if it is installed backwards. It will also burst if the voltage rating on the capacitor is less than the voltage in the circuit.

Caution: Protect your eyes from the capacitor bursting; wear goggles or other eye protection.

Redraw figure 1 on a separate piece of paper or your notebook. Pick out two resistors with values from 20 to 50 kΩ, and show these values on your drawing. You will duplicate the switch by connecting and disconnecting your jumper when you build the circuit.

1. Build the circuit in figure 1. Connect both switches, and use your DVOM to measure the voltage source. Record that voltage value on your paper.
   It should be close to 6 volts unless the batteries are getting weak.

2. Since both resistors are the same value, the voltage across the capacitor will be half of the voltage source. Measure this voltage, and verify that it is half of the source voltage.

3. Use the jumpers to connect your meter across the capacitor. You will need to have a watch or other timepiece handy. Open switch S_1, and wait until the voltage across the capacitor has dropped to zero. Now open switch S_2, and then close switch S_1.

   Record the time it takes for the voltage across the capacitor to increase to the voltage of the voltage source.

4. Open both switches, and notice that the voltage across the capacitor drops very slowly if at all. There is probably some leakage in the capacitor. Different capacitors will have different amounts of leakage.

5. Close switch S_1 until the capacitor is fully charged again, and then open S_1 and close S_2. Record the time it takes for the capacitor to discharge completely. *There should be no significant difference in time between the charge time and the discharge time.*

Exercise C-7

Semiconductor Diodes

1. How many electrons does silicon have in its outer orbit?
   four

2. What is the voltage drop across a PN junction in silicon?
   0.7 volt

3. What will happen if you forward-bias your LED by putting it directly across your 6-volt battery pack?
   With no resistance in series, the LED will fail.

4. What size of series resistor would be required in the circuit to limit the current in a typical LED if the voltage source is 14 volts?
   800 Ω

5. If the circuit puts a positive voltage at the common point for a seven-segment LED, what kind of seven-segment LED is it?
   common anode

6. What is the maximum current that most off-the-shelf LEDs can handle?
   20 mA

7. How is an SCR switched off?
   Remove the current flow through the device.

C-7 Semiconductor Diodes

Laboratory Experiment

Essential Elements: (gg) (1-3)

Objective

In this experiment, the student will examine the properties of diodes.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 silicon diode
1 light-emitting diode
1 1 kΩ resistor and 1 330Ω resistor (5% 1/4 watt)
1 DVOM

Procedure

The diode can be identified by examining figure 1. Notice that the black band around the body of the diode corresponds to the line across the tip of the symbol of the diode.

Identifying the proper leads on an LED will be a little harder (fig. 2). Sometimes it is necessary to simply put it in the circuit and, if it doesn't light, turn it around.

1. Use your jumper leads to build the circuit in figure 3. The voltage source should be your 6-volt battery supply. Use the 330Ω resistor in series with the diodes as shown. If the LED doesn't light, turn it around. The switch can be your connecting and disconnecting the jumper leads.

2. Use your DVOM to measure the voltage drop across the LED and across the silicon diode. Record these voltages in your notebook or other paper.

3. Measure the voltage drop across the resistor, and calculate the current for the circuit. Record this value in your notebook or paper.

4. Turn the diode around, and measure the voltage drop across the resistor. There should not be any voltage drop since there is no current flowing when the diode is reverse-biased.

5. Turn the diode around so it is forward-biased, and replace the 330Ω resistor with the 1 kΩ resistor. Notice that the LED is much dimmer. Measure and

record the voltage drops across the two diodes and the resistor. Compare these readings with the readings that you took earlier. Notice that the voltage drop across the diodes has changed only a little.

The junction will have a certain voltage drop with all current levels, and the rest of the diode provides some resistance, which will make a small change in the voltage drop across the whole device.

Exercise C-8

Transistors

1. Does the current flow in or out of the base of an NPN transistor (conventional current flow)?
   in

2. If a transistor has a beta of 200, how much current will be flowing through the collector with 0.5 mA of current flow through the base?
   0.1 A or 100 mA

3. If one transistor in a Darlington Pair has a beta of 150 and the other transistor has a beta of 30, what is the total current gain for the pair?
   4500

4. What value resistance should be put in the base circuit to protect the base emitter junction of a transistor that will be switching 500 mA with a signal input of 5 volts?
   86 Ω

5. What should the emitter resistance be for a switching transistor that will be controlling an LED that requires 15 mA? The signal input to the base will be 7 volts.
   420 Ω

6. How much current flows through the gate of a MOSFET transistor when it is controlling 100 mA of current?
   none

7. If a comparator is connected to the 12-volt supply in an automobile and has a fixed 4 volts on the plus input, what will the output voltage be with 3.6 volts on the minus input?
   12 volts

8. If a transistor has 6 volts on the base and a 1 kΩ resistor in the emitter, how much current will be flowing in the collector if the transistor is supplied by 12 volts?
   5.3 mA

C-8 Transistors

Laboratory Experiment

Essential Elements: (gg) (1-3)

Objective

In this experiment, the student will examine the properties of a comparator.

Equipment

1	6-volt voltage source (batteries and battery holder)
1	capacitor
2	resistors; both the same value and between 2 and 50 kΩ
1	1 kΩ resistor
1	comparator
1	socket for the comparator
1	DVOM

Procedure

The capacitor can be any size over 1 mF. Redraw figure 1 on a separate piece of paper or your notebook. Pick out the two resistors that are needed for the circuit, and show their values on your drawing. Add the 1 kΩ resistor to the output for a load. Connect this resistor from the output of the comparator to ground.

1. Build the circuit in figure 1.

2. Connect the plus input to 12 volts, and use your DVOM to measure the voltages on the two inputs and the output. Record these values in your notes.

3. Switch the plus input to ground, and measure and record the output voltage.

   The output voltage should have gone to zero when the plus input was connected to ground.

4. Change the circuit so the two resistors are on the plus input to the comparator. Do parts 2 and 3 over again, using the minus input instead of the plus input. Record the differences in output voltages in your notes.

   With the inputs reversed, the output voltage should be the opposite of the voltages you first recorded from parts 2 and 3.

Exercise C-9

Computer Circuits

1. Convert the following hexadecimal numbers to binary:
   $C7_{16}$, $2A_{16}$, 97_{16}, EF_{16}, $1C_{16}$
   11000111_2, 00101010_2, 10010111_2, 11101111_2, 00011100_2

2. Convert the following binary numbers to hexadecimal:
   00101110_2, 1111001_2, 111101_2
   $2E_{16}$, 79_{16}, $3D_{16}$

3. Give the output on each of the four logic gates, in figure 10, with the following inputs:

   a. A 0, B 1, C 1, D 1, E 1
   NOR gate 0 OR gate 1 AND gate 1 AND gate (final output) 0

   b. A 1, B 0, C 0, D 1, E 1
   NOR gate 1 OR gate 1 AND gate 1 AND gate (final output) 1

4. Use the following truth table to find the inputs that will show a different output between a two-input NAND gate and an OR gate with bubbles on both of its two inputs.

A	B	X
0	0	?
0	1	?
1	0	?
1	1	?

There is no difference between the two logic gates.

Exercise D-1

The Battery

1. In a fully charged lead acid battery, what is the material made of that coats the positive plate in the battery?
   lead peroxide

2. What two liquids make up the electrolyte in a lead acid battery?
   water and sulfuric acid

3. If a battery can deliver 345 amperes at 9.6 volts, what is the power rating of the battery?
   3,312 watts

4. What is the amp-hour rating of a battery that delivered 1.75 amperes for 20 hours at room temperature?
   35

5. What range of temperatures will have a negligible effect on hydrometer readings?
   70 to 90 degrees F

6. A fully charged good battery should read what voltage?
   12.6 volts

7. What is the maximum difference in specific gravity readings between cells that can be tolerated before a battery should be replaced?
   0.5

8. What should the specific gravity of a fully charged good battery be?
   1.265

9. What color is the negative plate in a fully charged lead acid battery?
   gray

10. A lead acid battery has 12.60 volts when it has no load on it. A load is placed across the battery, and the voltage drop across this 0.5 Ω load becomes 12.30 volts. What is the internal resistance of the battery?
    1.2 mΩ

D-1 The Battery

Laboratory Experiment

Essential Elements: (gg) (1-3)

Objective

The student will examine the internal resistance of a battery.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 47 Ω resistor
1 DVOM

Procedure

The automotive lead acid battery has a low internal resistance. All batteries have some internal resistance. A perfect voltage source does not have an internal resistance. You can think of a car battery and the flashlight batteries, that you will use with this lab, as perfect voltage sources in series with their internal resistance.

In order to accurately measure the value of the perfect voltage source inside the battery, you need to take an open circuit voltage measurement with a meter that draws very little current. Your DVOM is perfect for this application.

Once you have the open circuit voltage, you have the value of the perfect voltage source inside the battery. Next you will put a load on the battery and measure the output voltage. You will use this output voltage to calculate the current output from the battery. This voltage under load minus the open circuit voltage will give us the voltage drop across the internal resistance. The load current you calculated and the voltage drop across the internal load can be used to find the value of the internal resistance by using Ohm's law.

1. Connect your DVOM using two jumpers to the 6-volt battery pack, and accurately record the voltage of the battery pack with no load.

2. Switch your DVOM to resistance, and use two jumpers to accurately measure the value of the 47 Ω resistor.

3. Use the jumpers to connect the 47 Ω resistor to the battery pack. Switch your DVOM back to measure voltage, and carefully measure and record the voltage across the load. This is the voltage under load.

4. Now divide the voltage under load by the accurate value of the load resistance (47 Ω). Record this value. This is the current that is passing through the load and through the internal resistance in the battery.

5. Calculate the voltage drop across the internal resistance by finding the difference between the open circuit voltage and the voltage under load. Using Ohm's law again, divide this voltage difference, which is the voltage drop across the internal resistance, by the current that you calculated in part 4. The result is the internal resistance of the battery pack.

Exercise D-2

The Charging System

1. A technician obtains a new alternator off the shelf and puts it on the bench to test it. The technician connects the DVOM to the stator and spins the rotor. There is no voltage reading on the meter. Why does the DVOM show no voltage with the rotor spinning on a new good alternator?
   The rotor was not energized.

2. If the voltage regulator failed, allowing excessive current into the rotor, what kind of damage would result?
   High voltage from the alternator would damage the electronics on the car and overcharge the battery.

3. What three things in the design of an alternator will increase its performance?
   increase the speed of rotation, increase the number of turns in the windings, and increase the magnetic force from the rotor

4. What should the voltage on a fully charged battery be?
   12.6 volts

5. If the indicator lamp burns out in a charging system, what happens to the alternator?
   There is no current to energize the rotor so the alternator does not provide any current.

6. How can the driver tell when the belt driving the alternator breaks while the car is traveling down the road?
   The indicator or warning light will come on.

7. In figure 28, what would happen to the current through the field coil if the zener diode shorted?
   A large amount of current would pass through the field coil.

D-2 The Charging System

Laboratory Experiment

Essential Elements: **(gg) (1-3)**

Objective

In this lab, the student will examine the rectifier circuit used in an alternator.

Equipment

1 6-volt voltage source (batteries and 1 battery holder)
4 diodes
1 1 kΩ resistor
1 DVOM

Procedure

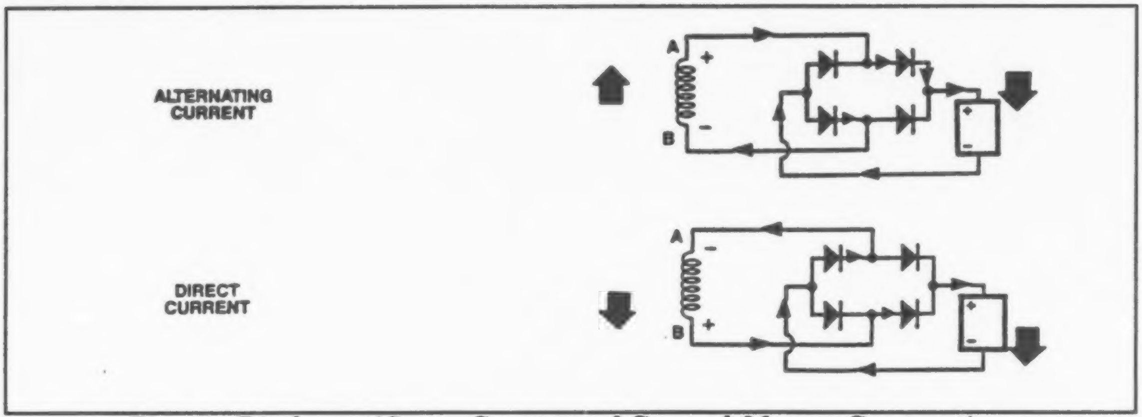

Fig. 1. Diode rectifiers. Courtesy of General Motors Corporation.

Figure 1 shows a typical rectifier circuit that would be part of an alternator. For this laboratory, you will substitute your 6-volt supply for the winding shown from point A to B. Substitute a 1 kΩ resistor for the box illustrating the battery in the drawing.

1. Draw the schematic using the symbol for a voltage source and resistor where you are going to substitute them, for the drawing at the top of figure 1.
2. Build the circuit that you have drawn in part 1.
3. Connect your DVOM's negative lead to the bottom of the 1 kΩ resistor, where figure 1 shows a negative terminal on the battery, and use the positive lead to

measure the voltages at all nodes. A node is where any component is connected or there is a connection between conductors. Record all of these voltage measurements with the polarity on your drawing.

4. Trace out the current path on your drawing based on the voltage measurements that you have recorded on the drawing.
5. Reverse the polarity on the 6-volt battery pack according to the drawing at the bottom of figure 1 and draw the schematic. Follow parts 1 through 4 above for the reverse polarity.

The current through the 1 kΩ resistor should always travel in the same direction, or from the top to the bottom, as shown in figure 21 in the assignment.

Exercise D-3

The Cranking System

1. What is the maximum acceptable voltage drop from the solenoid input terminal to the motor input terminal on a starter motor?
   0.3 volt

2. What will happen if the contact disk does not make contact with the terminals B and M?
   The motor will not crank the engine. The terminals B and M provide the direct connection to the battery for the motor.

3. How would the starter motor behave if the hold-in coil on the solenoid was open?
   The solenoid would pull in and then promptly release when the contact disk made contact with terminals B and M.

4. Examine figure 22, and determine which two terminals (Bat, S, M) would need to be shorted to crank the engine without operating the start switch.
   S and Bat

5. The typical resistance of the hold-in coil is 0.72 Ω, and the pull-in coil is 0.15 Ω. Examine the circuit in figure 23, and write the expected resistance values for the circuit between the following terminals. There are no external wires connected to terminals S, B, and M.
   a. S to G **answer is **0.72 Ω***
   b. S to B **answer is **open***
   c. S to M **answer is **0.15 Ω***
   d. B to M **answer is **open***

D-3 The Cranking System

Laboratory Experiment

Essential Elements: **(gg) (1, 3, 4)**

Objective

In this lab, the student will examine the problem caused by poor connections.

Equipment

1	6-volt voltage source (batteries and battery holder)
1	220 Ω resistor
1	variable resistor (10 kΩ pot)
1	DVOM

Procedure

A poor connection acts like a resistor to the current flow. The added resistance can be measured as a voltage drop. The amount of the voltage drop will depend on the amount of current and the amount of resistance. We will connect a variable resistor or potentiometer in series with a circuit from the voltage source to an LED and current limiting resistor. The variable resistor will represent a bad connection.

1. Use your jumpers to connect a 220 Ω resistor in series with the LED and connect this in series with the voltage source. Change the polarity at the voltage source if the LED does not light. Use your DVOM to measure the voltages at all nodes. Record all of the voltages that you have measured.

2. Now connect the pot in series with the LED and current limiting resistor (220 Ω), by connecting to the outside terminal and the center terminal.

3. Adjust the pot to about the midpoint, and use your DVOM to measure the voltages at all nodes. Record all your voltage measurements.

4. Look at your voltage measurements, and notice that the voltage drop across the pot is much larger than the voltage drop across your 220 Ω resistor. If the pot is a 10 kΩ, the midpoint on it will have added 5 kΩ of resistance. The voltage drop will increase or decrease with the resistance.

5. Adjust the pot until the LED is just barely on, and remeasure the voltage drop across the pot. Record this measurement. Next adjust the pot so the LED has a strong light, and measure the voltage drop across the pot. Record this measurement.

Notice how the voltage drop increases as the light decreases. On the starter motor circuit, as the resistance of a bad connection increases, the current to the motor and the ability of the motor to work will decrease.

Exercise E-1

Body Lights, Switches, and Related Systems

1. List the seven steps in the troubleshooting plan.
   (1) Determine the specific complaint.
   (2) Demonstrate the problem.
   (3) Stop and think!
   (4) Plan additional tests
   (5) Locate the problem.
   (6) Make the repair.
   (7) Test the repaired vehicle.

2. When taking voltage measurements to ground, you find that the voltage on one side of a 1 kΩ resistor is 12 volts and on the other side of the resistor the voltage is 10.5 volts. How much current is passing through this resistor?
   1.5 mA

3. A technician was using his DVOM to measure the resistance of a group of resistors. Upon completion of this, the technician immediately started testing a group of diodes. The diodes, although new, all appeared to be open. Why do the diodes all appear to be open?
   The resistance function on the DVOM does not have sufficient voltage to overcome the 0.7 volt junction barrier. No current will flow through the diode in either direction if the voltage is less than 0.7 volt.

4. What type of problem does a blown fuse usually indicate?
   short

5. A customer tells you that his backup lights do not work. You obtain the schematic (fig. 9) and examine it. Then you put the car into reverse and use your DVOM to test for voltage to ground at 3B. The voltage at 3B is the battery voltage. You then test at the bottom of the switch at the point B and C. You find the voltage is zero at this point. You take another reading at point A and C and find battery voltage. What has probably failed and needs to repaired or replaced?
   backup light switch

6. A new customer comes in and tells you that her backup lights do not work and the gauge fuse has blown. You remove the blown fuse, put the car in neutral, and use your DVOM to measure the resistance on the bottom side of the fuse socket. The reading is only a few ohms of resistance, indicating a short. When you look at the schematic (fig. 9), you notice that the current travels to a junction box (3B) after leaving the fuse block and then to the backup light switch. After the backup light switch, there is a long run of wire to the backup lights. Where should you test for the short next?
   The backup light switch is open with the car in neutral so the problem is prior to that. The junction box (3B) is halfway between the backup light switch and

the fuse block. Therefore, the junction box (3B) is the correct place to conduct your next test for the short.

E-1 Body Lights, Switches, and Related Systems

Laboratory Experiment

Essential Elements: **(gg) (1, 2, and 4)**

Objective

In this lab, the student will examine the problem of opens and shorts.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 220 Ω resistor
1 light-emitting diode
1 variable resistor (10 Ω pot)
1 DVOM

Procedure

1. Obtain a blank sheet of paper, and draw a schematic showing your 6-volt source in series with a 47 Ω resistor feeding a load which consists of a 220 Ω current limiting resistor in series with the LED. Assume that the LED will draw
   15 mA of current, and calculate the voltages to ground at all nodes. A node is a point where a component is connected or two or more conductors are connected. Record all of the voltage calculations on your schematic.

2. Build the circuit that you have drawn in part 1. If the LED does not light, use your DVOM to check the voltage across it. If the voltage across the LED is the supply voltage (6 volts), then it is either open or in backwards. Try turning it around.

3. Use your DVOM to measure the voltage drop across the 220 Ω resistor, and use this voltage and the resistance value to calculate the actual current drawn by the LED. Record this value, and measure all voltages at the nodes and record these values.

4. On the schematic that you have drawn, assume that there is a short to ground from a point between the 220 Ω resistor and the LED to ground. Draw this short in on your schematic, and calculate the voltages that you will expect at all nodes. Record all of this on your schematic.

5. Take one of your jumpers, and put the short into your circuit as you have drawn it on your schematic. Measure all of the voltages on the nodes, and compare them with your calculated values.

6. Cross out the short on your schematic, and show an open between the two resistors. Calculate the voltages at all nodes, and record them.

7. Remove the short from your circuit, and open the circuit where you have made the open in your schematic. Measure all voltages at the nodes, and compare them with your calculated values.

This laboratory should have helped you to understand how voltage measurements will change with a short or open in a series circuit. A short or open is common in some older vehicles, usually in the circuits feeding the lights where long runs of wire are involved.

Exercise E-2

Instrument Panel

1. What is the circuit called that changes analog signals to digital signals?
   A/D converter or analog/digital converter

2. How many pulses are sent to the stepper motor in an odometer for each mile traveled?
   2,002

3. Which type of memory chip can be changed in a special fixture?
   PROM

4. What are the initials for the three common types of electronic instrument panels.
   LED, LCD, and VFD

5. What happens differently when a halogen bulb breaks than when an ordinary bulb breaks?
   The halogen bulb, when broken, is under pressure and will fly out instead of in, like an ordinary bulb.

6. How many conductors are in the data bus going to the microprocessor?
   8

7. Which memory type can the microprocessor use to store information in and read it back out?
   RAM

E-2 Instrument Panel

Workbook

Essential Elements: **(gg) (1-4)**

Objective

To practice troubleshooting skills on the Corvette instrument panel

Procedure

The schematic in figure 1 shows the instrument panel connections. Four fuses are shown across the top of the drawing. Each of the inputs to the cluster is numbered and the wires are all identified. The inputs are all grouped in either the C plug or the D plug. The A and B plugs come from the function select switches.

Examine figure 1, and answer the following questions.

1. What is the color of the wire that goes from the fuel sensor in the fuel tank to the instrument panel?
   pink

2. If the instrument panel suddenly lost its illumination, where would you look for the problem first?
   INST LPS fuse

3. A customer just returned from Canada with her Corvette and complained that the instrument panel did not respond properly until the interior of the car was warm. What component would probably be the problem?
   Ambient Temp Switch

4. In figure 1, which wire would you check if the left turn signal stopped working?
   light blue wire from the second pin on the C plug.

Exercise E-3

Vehicle Restraint Systems

1. What is the difference between an active and a passive restraint system?
   The active requires action by the occupant, and the passive is automatic with no action required by the occupant.

2. How fast do you have to be going when you run into a parked car that is about equal to your car in weight and size for the air bags to deploy?
   28 mph

3. How long does it take for the air bag to completely inflate after impact?
   65 milliseconds

4. How many times can an air bag be used before it should be replaced?
   only one time

5. How many of the crash sensors and safing sensors have to make contact to deploy the air bag?
   one crash and one safing sensor

6. If you enter a Ford vehicle with an air bag system installed and you find the air bag ready light is flashing, what does this mean?
   The system has a fault.

7. When a vehicle has an air bag system for both the driver and passenger, is there any need for seat belts?
   Yes, the air bag only operates in a severe crash, and the occupants would need the seat belts in a less severe crash. Also, the seat belts keep the occupants in position to take advantage of the air bags.

Workbook

Essential Elements: **(gg) (1, 2, and 4)**

Procedure

Use figure 1 and table 1 to determine how the seat belt system will respond to the following actions. Write your answer on a separate piece of paper, and then compare your answers with the answers given at the end of the lesson.

1. With the car door closed, the ignition switch is turned on.
   The seat belt will move to the "B" pillar.

2. With the ignition switch in the off position, the door is opened.
   The seat belt will move to the "A" pillar.

3. The door is open, and the ignition switch is turned on.
   There will be no seat belt movement.

4. With the door closed, the ignition switch is turned on.
   The seat belt will move to the "B" pillar.

5. With the inertia switch in the open condition and the door open, the ignition switch is turned on.
   There will be no seat belt movement.

6. With the inertia switch in the open condition and the door open, the ignition switch is turned off.
   The seat belt will move to the "A" pillar.

Assume that you are troubleshooting this seat belt system, and use figure 1 and table 1 to determine what you should do next.

7. You can hear the transport motor run, but the seat belt does not move although you can move it manually.
   Open up the system, and check the belt that pulls the seat belt along. It is probably broken.

8. When the door is closed with the ignition either on or off, the seat belt moves to "B" pillar.
   The solid-state module that controls the system is probably at fault. Use the manufacturer's service material to determine what procedure you should use to confirm the failure of this module. If it has failed, then replace it.

Exercise F-1

Automotive Sensors

1. If the reference voltage is 6 volts in figure 23, the current limiting resistor is 100 kΩ, and the thermistor is 50 kΩ, what is the voltage that is sent to the microprocessor?
   6 volts

2. Using the values from question 1, what would the voltage be, referenced to ground, at the bottom of the thermistor?
   6 volts

3. If the current limiting resistor in figure 24 is 50 kΩ, the thermistor is 30 kΩ, and the reference voltage is 12 volts, what is the voltage sent to the microprocessor?
   0 volts

4. When the short in figure 24 is repaired, what voltage will be sent to the microprocessor, using the values given in question 3?
   4.5 volts

5. If a thermistor with a positive temperature coefficient goes from 80°F to 150°F, what will happen to the resistance of the device?
   It will go up.

6. What is the minimum operating temperature of an oxygen sensor?
   600°F

Exercise F-2

Engine Fuel Delivery Systems

1. When the ECA is operating "OPEN LOOP," which input sensor is ignored?
   oxygen sensor

2. In a fuel-injected system, which output from the ECA is the most important output for controlling the air-fuel ratio?
   injectors

3. What is the approximate pressure of the fuel in the lines going to the engine?
   40 psi

4. If the driver pushes the throttle to the floor, what information from the oxygen sensor is used by the ECA?
   None, the system goes open loop.

5. Explain why the car may have poor drivability or run rough after the owner has the battery changed.
   The loss of power from changing the battery will have destroyed the learned data. The car will be operating on the default data until it can relearn the data.

6. A technician is having trouble starting a diesel car. The technician notices that the voltage going to the glow plugs is intermittent. The technician decides to connect battery voltage directly to the glow plugs in order to start the car. What components will have to be changed?
   All of the glow plugs will be burned and will have to be changed.

7. What sensor input is used on a glow plug system in a diesel car?
   engine coolant temperature

F-2 Engine Fuel Delivery Systems

Workbook

Essential Elements: (gg)(1, 2, 4 , and 5)

Figure 1 shows the electrical schematic for a typical electronically controlled fuel-injected engine. The lines going to small circles with numbers show the pin numbers for the connector to the ECA or computer. The components across the top are the input sensors for the system.

1. Take a separate piece of paper, and redraw the schematic for the circuit to the fuel pump. Note that there is continuity through the plug located at the bottom center of the drawing.

2. We can assume that there is no resistance in the plugs or the inertia switch in the fuel pump circuit, and that the fuel pump draws 3 amp. Assume that the battery voltage is 12.4 volts, and calculate the voltage measured to ground at the input to the fuel pump, located at the number 787.
   8.5 volts

3. Locate and record the pin numbers on the harness connector that go to ground.
   7 and 8

4. Look at the wire color information at the bottom right of figure 1. Use a separate piece of paper to write the colors of the wires coming from the following pin numbers on the harness connector: 23, 4, 18, 29, 9, 12.

   23—Dark green wire with purple hash
   4—Brown wire with light green stripe
   18—Dark blue wire
   29—Yellow wire
   9—Light green wire with black hash
   12—Tan wire with red dots

Exercise F-3

Ignition Systems

1. For the conventional electronic ignition system, how many high-voltage pulses per minute will each spark plug receive if the engine is running at 1,000 rpm? How many for the direct ignition system?
   500, 1000

2. What is the minimum ac voltage output from a magnetic sensor on the crankshaft under cranking conditions for a 2.8L engine?
   100 mV

3. A technician was troubleshooting a problem with the ignition system. The technician found that the cylinder pair 2 and 5 did not fire. To check the coil, the technician connected battery voltage to the primary of the coil with no results. Then the technician noticed that one of the spark plugs had broken. When the plug was replaced, the companion pair still did not fire. What is the most probable reason for the companion pair not firing now?
   The technician burned out the primary of the coil with the battery voltage.

4. What two inputs have to be present before a Hall effect device will output voltage?
   magnetic force and current

5. What material is used to make Hall effect devices?
   silicon semiconductor material

6. How does the GM 3.8L turbo engine determine the correct sequence for firing the companion pair spark plugs?
   The correct sequence for the GM 3.8L turbo engine is determined by adding an additional Hall effect sensor on the cam.

F-3 Ignition Systems

Workbook

Essential Elements: (gg)(1, 2, 4, and 5)

Figure 1 shows a schematic of the ignition computer module connections. Notice that the direct ignition system module has three plugs shown above and on the right side of the module. The two pin plug is at the top of the module shown connected to engine ground and battery voltage through the ECM fuse and IGN or ignition switch assembly. The crank sensor is the type that uses a magnet inside a coil of wire. The signal output from this sensor will look like the drawing in figure 7 in the assignment, which you studied earlier.

1. Refer to figure 7, and draw the signal that you would expect to see coming from the crank sensor in figure 1. Draw the signal for one complete revolution from the crankshaft.

2. Redraw the inside of the direct ignition system module using transistors instead of the switches to control the input to the primary of the coils. The transistors should have their emitters connected to ground, the collector connected to the primary of the coil, and the base will be the input from the internal electronics in the module.

3. Draw the crankshaft as shown in figure 1, and show on the drawing which coil will be fired at which notch on the crankshaft. Note that there are only three coils since the coils fire the two companion cylinders for this six-cylinder engine.

The drawing for problem 1 should show seven complete sine waves with two close together to show the double notch. The drawing for problem 2 should show the three transistors connected as described in the problem. The drawing for problem 3 should show the cylinder pairs as shown in figure 9 in the assignment.

Exercise F-4

Emission Control Systems

1. If the combustion process were perfect, what two compounds would be the only product of this combustion?
   water and carbon dioxide

2. What are the five general systems that are used for control of harmful emissions?
   (1) positive crankcase ventilation (PCV) system
   (2) secondary air (Thermactor) systems
   (3) IMCO (improved combustion) system
   (4) evaporative control system
   (5) exhaust gas recirculating (EGR) system

3. Which system is used to reduce the amount of nitrogen oxides in the exhaust gases?
   exhaust gas recirculating (EGR) system

4. Which sensor is critical to the operation of the feedback network or closed loop operation?
   oxygen sensor

5. What engine condition will generate carbon monoxide?
   lean engine

F-4 Emission Control Systems

Laboratory Experiment

Essential Elements: (gg)(1, 2, 4, and 5)

Objective

Students will determine if the potentiometer they are using in this lab is linear or nonlinear.

Equipment

1 potentiometer
1 DVOM
Paper, wooden pencil, or other stick for a pointer

Procedure

To determine if the pot is linear or nonlinear, you will plot the change in resistance against the change in position of the wiper or the control on the pot. If the line on the graph that you plot is a straight line, the pot is linear. If the line is curved, the pot is nonlinear.

1. Start by attaching a wooden pencil or other suitable pointer to the shaft on the potentiometer so you can read the position of the control. Attach it with string or a rubber band so that it does not move and give you an erroneous reading.

2. Place a piece of paper under the pot, and move the control all the way in both directions, noting the size of the arc that it moves through. Draw a circle showing this amount of arc, and divide this arc into ten *equal* sections.

3. Take another piece of paper, and draw a horizontal line. On the right end of this line, draw a vertical line. Label the horizontal line as the control movement, and divide it into ten sections.

4. Measure the total resistance of the pot by using your DVOM and reading between the two outside terminals.

5. Put the maximum resistance reading from part 4 at the top of the vertical line. Divide the vertical line into ten sections, and label each section with the resistance. The bottom of the vertical line should show 0 Ω. The first section up should show 10% of the total resistance. The next section should show 20% of the total resistance.

6. Now adjust the control of the pot to the first segment, and read the resistance. If the resistance is high, use the other outside terminal. Make a mark on your graph to show where the resistance and the position lines would cross. Do this with the other nine segments on your graph.

If the line that connects these ten marks on your graph is mostly a straight line, the pot is a linear pot. If the line has a strong curve to it, the pot is nonlinear. The most common nonlinear pot has a logarithmic taper to it, or it changes at a logarithmic rate.

Exercise G-1

Cruise Control

1. What is the MSLO for most Ford cars?
   30 mph

2. If a driver momentarily presses the brake while operating the cruise control, what button can the driver press to regain and maintain the orginal speed set on the cruise control?
   RESUME

3. In figure 18, if the HORN RELAY COIL is 800 Ω, and the COAST resistor is 680 Ω, what will the voltage be at SCCS connection to the EEC IV PROCESSOR? Assume that the V BAT is 12 volts and that all other switches are open except the ON switch.
   5.5 volts

4. What is the voltage at the SCCS connection to the EEC IV PROCESSOR in figure 18 when the HORN switch is closed?
   0 volts

5. In figure 18, what is the voltage at connection B00 when the stoplamp switch is open and closed?
   0 volts and 12 volts

G-1 Cruise Control

Laboratory Experiment

Essential Elements: (gg) (1, 2, and 4)

Objective

This lab will help you understand the driver-controlled switches that control the speed control system.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 120 Ω resistor
1 680 Ω resistor
1 2.2 kΩ resistor
1 1 kΩ resistor
1 DVOM

Procedure

Examine the schematic in figure 1, and notice the location of the V BAT, HORN RELAY COIL, RESUME resistor, ACCEL resistor, COAST resistor, the OFF switch, the ON switch, and the SCCS GROUND. Also notice the SCCS line which goes into the EEC IV PROCESSOR (computer module).

1. Redraw the part of the circuit in figure 1 that includes the components listed above. Leave the circuit open at the HORN switch. Do not include the two fuses, the STOPLAMP SWITCH, or the KA PWR and V PWR lines. Where the SCCS line connects to the EEC, show that line connected to your DVOM with the negative lead of the DVOM connected to ground. Show the V BAT as your 6-volt battery source. The SCCS GROUND will connect back to the negative terminal on your 6-volt supply.

2. Label the resistors on your drawing showing 120 Ω for COAST, 680 Ω for ACCEL, and the 2.2 kΩ for RESUME. Make a notation that the HORN RELAY COIL will be replaced with a 1 kΩ resistor.

3. Use your components to build the circuit that you have just drawn.

4. Make a chart to record the voltage levels for the OFF switch, COAST, ACCEL, and RESUME switches. You can just connect and disconnect each resistor with your jumper leads to simulate the switches. Calculate and record the voltages that you expect to read when you measure these voltages.

5. Measure and record the voltage levels for each of the switch positions on your chart. Compare these measurements with the calculated values. Go back over your calculations if there is a significant difference between the calculated value and the measured value.
6. Measure these voltages again with the 1 kΩ resistor both open and shorted to simulate two fault conditions.

Exercise G-2

Electronic Gearshift Transmissions

1. How many output solenoids does the controller control?
   4

2. If the controller sees a serious fault with the transaxle system, what does it do?
   It locks into second gear when the gearshift lever is moved to a forward gear.

3. After completing its checkout of the system, what is the first component that the controller send battery current to?
   The controller sends battery voltage to the solenoid shutdown relay.

4. What are the six pressure switches used for?
   The pressure switches are only used to confirm the proper operation of the transaxle by monitoring the solenoids.

G-2 Electronic Gearshift Transmissions

Workbook

Essential Elements: (gg) (1, 2, and 4)

Figure 1 shows the electrical drawing for the transaxle that you have been examining in the assignment. The CCD BUS is used to carry information from the engine controller or computer to the transaxle controller or computer.

1. There are two batteries shown in this schematic. Both of these batteries are actually the same battery that is drawn in two locations for simplicity. Locate the battery on the left side near the top of the drawing. Write the names of the components that the current will pass through, when energizing the STARTER RELAY, from the battery to ground.
   battery, fuse link, ignition switch, starter relay, neutral safety switch, and ground

2. List the components that the current will pass through to light the backup lamps.
   battery, fuse link, ignition switch, backup lamp relay, backup lamps, and ground

Exercise G-3

Antilock Brake Systems

1. What is the minimum and maximum wheel slippage that should be allowed by a good antilock brake system?
   8% to 35%

2. If the front wheel of a vehicle is doing 10 revolutions per second, what frequency would be coming from the antilock brake sensor if the rotor has 96 serrations?
   96 times 10 = 9,600

3. What three current levels are used to control the three-position solenoid valve?
   0, 2, and 5 amp

4. How do you read the fault codes from memory on an antilock brake system?
   To read the fault code in memory, first turn the ignition on, and then disconnect the actuator check connector. The fault codes stored in memory will be flashed on the antilock light.

5. How long is the pause before the antilock light starts repeating the fault codes?
   There will be a 4-second pause before it starts over.

6. After the antilock brake system is repaired, how can you clear the fault codes from memory and restore the antilock light?
   The antilock light and the fault codes in memory can be cleared by turning the ignition on with the actuator check connector disconnected and pumping the brake pedal so the light comes on eight or more times within 3 seconds.

G-3 Antilock Brake Systems

Workbook

Essential Elements: (gg) (1, 2, and 4)

Figure 1 shows the electrical wiring for a Toyota Supra. Notice the three speed sensors on the right side of the computer. This system has four solenoids in the actuator, a motor relay, and a solenoid relay.

1. List the components that the current will pass through from the ignition switch to the SB input to the computer.
   ignition switch, antilock warning light, actuator, check connector, diode, bypass Sol., and SB connection to the computer

2. With the solenoid relay energized, what is the current path from the battery to the SFL connection on the computer?
   battery, two inline fuses, F.L. A.B.S. (fuse), solenoid relay, RR SOL, SFL connection

Answers
to
Unit Tests

Unit A Test

Introduction

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1. The four parts of an assignment are (1) the objectives, (2) the technical information, (3) the exercise, and (4) the test.
2. You should read the objectives first so you will know what is important in the assignment.
3. Serious injury in the shop may be avoided if the shop is kept cleaned and orderly and safety practices are observed.
4. Most training authorities recommend that persons seeking a job as a beginning trainee complete a formal training program.
5. In addition to engine controls and dashboard instruments, electronic components are now found in the brake, transmission, and steering systems.
6. Many employers send experienced technicians to factory training centers to receive special training.
7. Growing technology requires that automobiles be serviced by professional technicians.
8. Changes in economic conditions have little effect on the automotive repair business.
9. Going into a business can be considered a high-risk gamble.
10. When considering a neighborhood for a business, empty buildings are bad neighbors.
11. When starting a new business, you are the first and most important source of capital.
12. Money used to pay bills is called working capital.
13. Paying bills by check is absolutely necessary because canceled checks are proof of payment.
14. The most common type of shop ownership is sole proprietorship.
15. Even with trusted friends and family member, you should hire an attorney to draw up a partnership agreement.
16. Four kinds of essential insurance of a shop are (1) fire insurance, (2) automobile insurance , (3) liability insurance, and (4) workers' compensation insurance.

17. The single greatest expense of operating a business is salaries.

18. When considering how much to pay employees, it is good to remember the old saying, *you get what you pay for*.

19. Paying automotive technicians a commission develops incentive.

20. Fringe benefits are services and goods received in addition to normal wages or salary and tend to encourage productivity and loyalty.

Unit B Test

Safety and Tools

---

1. One of the primary causes of accidents is a careless attitude toward safety practices.

2. The leg muscles should be used to lift heavy loads correctly.

3. Open flames near a battery should be avoided because gases formed during charging are explosive.

4. Test equipment should be connected and disconnected to subassemblies of an engine when the engine is not running.

5. Loose clothing should not be worn in the shop because it may get caught in the machinery.

6. If they are not double-insulated, electrically powered tools should be equipped with a three-wire connector.

7. Offset screwdrivers are used where there is not enough clearance to use a standard screwdriver.

8. Soft hammers and mallets are used to pound or drive objects or perform other operations where a steel hammer would mar or perhaps break the work.

9. Diagonal pliers are used to cut and strip insulation wire, cut cotter pins to the proper length, spread cotter pins, and cut off wire close to terminals.

10. The head of an open-end wrench is cast at 30° offset from the handle to allow the wrench to be used in a restricted area.

11. A torque handle is used to regulate the amount of force applied to the nut.

12. The contact points of inside micrometers are slightly rounded to permit accurate contact with either parallel surfaces or inside curved surfaces.

13. Calipers are actually designed to transfer measurements from measuring tools to the work or from the work to measuring tools.

14. One of the first precautions to be taken with any power tool is to read the operating instructions supplied by the manufacturer.

15. An impact socket is distinguished from a regular socket because it is usually flat black, and a regular socket is usually chrome.

Unit C Test

Basic Electricity and Electronics

---

1. What is a volt?

   A. A volt is defined as the EMF that is in one electron.
   B. A volt is defined as the EMF in one coulomb of charge.
   C. A volt is defined as 1 million electrons passing a point in one second.
   D. A volt is defined as the pressure that will move 1 amp of current.
   E. None of the above

   B

2. What is an amp?

   A. An amp is defined as one electron passing a point in one second.
   B. An amp is defined as one coulomb of electrons passing a point in one minute.
   C. An amp is defined as one coulomb of electrons passing a point in one second.
   D. An amp is defined as the number of electrons that will move under the pressure of one volt.
   E. None of the above

   C

3. What is an ohm?

   A. An ohm is defined as the amount of resistance that will oppose one amp of current.
   B. An ohm is defined as the unit of resistance that will oppose one volt of current when there is only one volt of pressure.
   C. An ohm is defined as the unit of resistance that will only allow one amp of current when there is only one volt of pressure.
   D. An ohm is defined as the resistance that will stop one coulomb of electrons from passing a point in one minute.
   E. None of the above

   C

4. Which of the following are the formulas for Ohm's law?

   A. $E = IR$, $I = E/R$, $R = E/I$
   B. $E = I/R$, $I = ER$, $R = E/I$
   C. $E = IR$, $I = ER$, $R = E/I$
   D. $E = RI$, $I = R/E$, $R = E/I$
   E. None of the above

A

5. If a DVOM with an accuracy specification of (1.0% + 2d) shows a reading of 11.5 V, what is the range of possible true voltages?

   A. 11.3 to 11.7
   B. 11.2 to 11.8
   C. 11.1 to 11.9
   D. 11.0 to 12.0
   E. None of the above

   B

6. If a circuit has 3.6 kΩ in series with 8 MΩ and a 16-volt source, how much current will flow through this circuit?

   2 mA

7. A circuit with 14.4 volts in series with the parallel combination of 1 kΩ and 3 kΩ resistors will have what current coming from the voltage source?

   19.2 mA

8. A circuit has a source voltage pushing 2.5 mA of current through a 3 kΩ resistor in series with the parallel combination of 4 kΩ and 6 kΩ. What is the value of the source voltage?

   13.5 volts

9. Why should you avoid splicing a copper wire to an aluminum wire?

   A. Galvanic corrosion will result.
   B. The aluminum wire is a poor conductor of electricity.
   C. The copper wire is heavier and more expensive.
   D. The aluminum wire will become too stressed.
   E. None of the above

   A

10. What is the minimum allowable distance between a splice that you make and other splices, connectors, and branches in the harness?

    1 1/2 inches

11. When installing a fusible link, what wire gauge size of fusible link wire should you use to connect with a particular harness wire?

    A. Six wire gauges smaller than the wire harness.
    B. Two wire gauges larger than the wire harness.

C. The same wire gauge size as the wire harness.
D. Four wire gauges smaller than the wire harness.
E. None of the above

D

12. If we triple the number of turns of wire wrapped around an electromagnet, what will happen to the magnetic force?

A. It will increase.
B. It will decrease by half.
C. It will remain the same.
D. It will become saturated.
E. None of the above

A

13. What is the frequency of a sine wave that takes 10 ms to complete 5 cycles or waves?

500 kHz

14. What is the dc equivalent voltage for 18 peak volts, when the amount of work they can do is compared?

12.7 volts

15. If one sine wave on the screen of an oscilloscope takes 3.2 horizontal divisions and the Time/Div control is on 2.5 ms per division, what is the frequency of the signal?

125 kHz

16. Two signals on a dual trace scope each take 3.5 divisions horizontally for one wave and are 0.7 division different at the point they cross the center line. How many degrees are they out of phase?

72 degrees

17. What is the voltage drop across a silicon PN junction?

0.7 volt

18. What should the value of a series resistor be to limit the current through a typical LED if the voltage source is 16 volts? Give the calculated value of resistance.

933 Ω

19. A transistor with a beta of 300 will have how much current flowing through the collector with 0.2 mA of current flow through the base?

60 mA

20. If the transistors in a darlington pair have betas of 200 and 25, what will be the total current gain for the pair?

5,000

21. What should the value of the resistance be in the base circuit to protect the base emitter junction of a transistor that will be switching 750 mA with a signal input of 6 volts?

80 Ω

22. What should the emitter resistance be for a switching transistor that will be controlling two LEDs in parallel that require a total of 30 mA? The signal parallel input to the base will be 4 volts.

110 Ω

23. What is the gate current in a MOSFET that is controlling 150 mA of current?

none

24. A comparator is connected to a supply of 16 volts and ground. It has a fixed 5 volts on the minus input. What will the output voltage be with 3.6 volts on the plus input?

0 volts

25. A two-input (A and B) AND gate has its output connected to one input of a two-input NOR gate. (Input C is still free.) This gives a total of three inputs to the circuit (A, B, and C). List all of the logic possibilities that will give a logic 1 on the output of this circuit.

A = 0, B = 1, C = 0
A = 1, B = 0, C = 0

Unit D Test

Engine Electrical Systems

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1. If a battery can deliver 320 amperes at 10.2 volts, what is the power rating of the battery?

   3,264 watts

2. What is the amp-hour (AH) rating of a battery that delivered 1.20 amperes for 20 hours at room temperature?

   24

3. A battery that is fully charged should have what voltage across its terminals?

   12.6 volts

4. A battery should be replaced when the specific gravity readings differ between cells. How much of a difference is too much?

   0.5

5. What should the specific gravity of a fully charged cell in a good battery be?

   1.265

6. When you look inside a fully charged good battery, what color is the negative plate?

   gray

7. A car battery with no load across it has 12.50 volts between its terminals. When a load is placed across the battery, the voltage drop across the 0.4Ω load becomes 12.25 volts. What is the internal resistance of the battery?

   8 mΩ

8. What three design changes can be made to an alternator to increase its performance?

   A. Use a larger pinion gear, use heavier metal on the case, and run it faster.
   B. Use a larger contact disk, increase the size of the armature, and shorten the plunger stroke.
   C. Increase the speed of rotation, increase the number of turns in the windings, and increase the magnetic force from the rotor.
   D. Use roller bearings, spin the armature slower, and lower the current input.
   E. None of the above

C

9. What will happen if the contact disk does not release from making contact with the terminals B and M?

   A. The motor will stop running.
   B. The solenoid will burn up.
   C. The motor will run continuously.
   D. The pull-in winding will burn open.
   E. None of the above

   C

10. How would the starter motor behave if the pull-in coil on the solenoid was open?

   A. The starter motor would run backwards.
   B. The solenoid would immediately get hot and probably burn up.
   C. The solenoid would slowly, if at all, pull in, and when it was pulled in, the motor would crank in a normal manner.
   D. The solenoid would vibrate in and out.
   E. None of the above

   C

Unit E Test

Body Electrical Systems

---

1. Which of the following is **not** part of the seven steps to the troubleshooting plan?

   1. Determine the specific complaint.
   2. Demonstrate the problem.
   3. Test all of the potential problem components.
   4. Plan additional tests.
   5. Locate the problem.
   6. Make the repair.
   7. Test the repaired vehicle.

   3. Test all of the potential problem complaints.

2. What is an A/D converter?

   It is a circuit that changes analog signals to digital signals.

3. How many miles have been traveled if 5,005 pulses have been sent to the stepper motor in an odometer?

   2 1/2 miles

4. Arrange the three basic types of memory chips (RAM, ROM PROM) next to the statement which bests describes them.

   A. Read write memory—RAM
   B. Can be read from only—ROM
   C. Can be programmed in a fixture—PROM

5. The halogen bulb, unlike most ordinary bulbs, is under a positive pressure. Ordinary bulbs have a vacuum inside them. How does this pressure cause them to be more dangerous?

   The halogen bulb, when broken, will fly out instead of in, like an ordinary bulb.

6. What are the two broad catagories for seat belts that you actively put on and belts that automatically wrap around you?

   (1) active and (2) passive

7. What is the minimum speed that will cause the air bags to deploy, when you run into a parked car that is about the same size as your car?

28 mph

8. What is the length of time that it takes for the air bags to completely inflate from the moment of impact?

   65 milliseconds

9. When should an air bag be replaced?

   after one use

10. Does the air bag system replace the need for seat belts? Explain.

    No, the air bag only operates in a severe crash, and the occupants would need the seat belts in a less severe crash. Also, the seat belts keep the occupants in position to take advantage of the air bags.

Unit F Test

Engine Electronic Control Systems

1. If a thermistor that is used for measuring coolant temperature, with a positive temperature coefficient, goes from 120°F to 75°F, what will happen to the resistance of the device?

   It will go down.

2. What temperature does an oxygen sensor have to reach before it will start sending valid data?

   600°F

3. Which input sensor is ignored when the ECA (computer module) is operating "OPEN LOOP"?

   oxygen sensor

4. Which output from the ECA (computer module), in a fuel-injected system, has the greatest effect on the fuel-air ratio?

   injectors

5. Approximately, what is the fuel pressure in the fuel lines going to the engine?

   40 psi

6. What happens to the data that is received by the computer module from the oxygen sensor when the driver pushes the throttle to the floor?

   The data is not used; the system goes open loop.

7. What input sensor is used to control the glow plug system in a diesel car?

   engine coolant temperature

8. In a direct ignition system, how many high-voltage pulses per minute will each spark plug receive if the engine is running at 500 rpm?

   500

9. What are the two inputs to a Hall effect switch that are required before the switch will output voltage?

   magnetic force and current

10. What is a Hall effect device made from?

silicon semiconductor material

11. If the gasoline and air were combined or burned perfectly in an engine, what are the only two compounds that would be the product of this combustion?

water and carbon dioxide

12. Which one of the emission control systems is used to reduce the quantity of nitrogen oxides emitted?

exhaust gas recirculating (EGR) system

13. What engine condition will generate unburned hydrocarbons?

rich engine

Unit Tests

Unit A Test

Introduction

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1. The four parts of an assignment are (1) the ____________, (2) the ______________, (3) the _____________, (4) and the __________________.

2. You should read the ______________ first so you will know what is important in the assignment.

3. Serious injury in the shop may be avoided if the shop is kept cleaned and orderly and _________________ are observed.

4. Most training authorities recommend that persons seeking a job as a beginning trainee complete a formal ___________________.

5. In addition to engine controls and dashboard instruments, electronic components are now found in the ____________, ____________, and ___________.

6. Many employers send experienced technicians to ____________________________ to receive special training.

7. Growing technology requires that automobiles be serviced by _________________.

8. Changes in economic conditions have ___________________________ effect on the automotive repair business.

9. Going into a business can be considered a ___________________ gamble.

10. When considering a neighborhood for a business, empty buildings are _________________.

11. When starting a new business, ________________________are the first and most important source of capital.

12. Money used to pay bills is called ___________________ capital.

13. Paying bills by check is absolutely necessary because canceled checks are _____________________________________.

14. The most common type of shop ownership is ___________________________.

15. Even with trusted friends and family member, you should hire _______________ to draw up a partnership agreement.

16. Four kinds of essential insurance of a shop are (1) fire insurance, (2) automobile insurance, (3)___________________, and (4)_____________________________.

17. The single greatest expense of operating a business is ______________.

18. When considering how much to pay employees, it is good to remember the old saying, ____.

19. Paying automotive technicians a ___________________ develops incentive.

20. ___________________ are services and goods received in addition to normal wages or salary and tend to encourage productivity and loyalty.

Unit B Test

Safety and Tools

---

1. One of the primary causes of accidents is a ______________________________.
2. The ______________ muscles should be used to lift heavy loads correctly.
3. Open flames near a battery should be avoided because gases formed during charging are __________________.
4. Test equipment should be connected and disconnected to subassemblies of an engine when the engine is ______________________________.
5. Loose clothing should not be worn in the shop because it may get ____________ in the machinery.
6. If they are not double-insulated, electrically powered tools should be equipped with a ____________________.
7. ____________ screwdrivers are used where there is not enough clearance to use a standard screwdriver.
8. __________________________ are used to pound or drive objects or perform other operations where a steel hammer would mar or perhaps break the work.
9. ____________ are used to cut and strip insulation wire, cut cotter pins to the proper length, spread cotter pins, and cut off wire close to terminals.
10. The head of an open-end wrench is cast at 30° offset from the handle to allow the wrench to be used in a ________________.
11. A ________________ is used to regulate the amount of force applied to the nut.
12. The contact points of inside micrometers are slightly ______________ to permit accurate contact with either parallel surfaces or inside curved surfaces.
13. Calipers are actually designed to ________________________ from measuring tools to the work or from the work to measuring tools.
14. One of the first precautions to be taken with any power tool is to __________________ supplied by the manufacturer.
15. An impact socket is distinguished from a regular socket because it is usually ______________, and a regular socket is usually chrome.

Unit C Test

Basic Electricity and Electronics

1. What is a volt?

   A. A volt is defined as the EMF that is in one electron.
   B. A volt is defined as the EMF in one coulomb of charge.
   C. A volt is defined as 1 million electrons passing a point in one second.
   D. A volt is defined as the pressure that will move 1 amp of current.
   E. None of the above

2. What is an amp?

   A. An amp is defined as one electron passing a point in one second.
   B. An amp is defined as one coulomb of electrons passing a point in one minute.
   C. An amp is defined as one coulomb of electrons passing a point in one second.
   D. An amp is defined as the number of electrons that will move under the pressure of one volt.
   E. None of the above

3. What is an ohm?

   A. An ohm is defined as the amount of resistance that will oppose one amp of current.
   B. An ohm is defined as the unit of resistance that will oppose one volt of current when there is only one volt of pressure.
   C. An ohm is defined as the unit of resistance that will only allow one amp of current when there is only one volt of pressure.
   D. An ohm is defined as the resistance that will stop one coulomb of electrons from passing a point in one minute.
   E. None of the above

4. Which of the following are the formulas for Ohm's law?

   A. $E = IR$, $I = E/R$, $R = E/I$
   B. $E = I/R$, $I = ER$, $R = E/I$
   C. $E = IR$, $I = ER$, $R = E/I$
   D. $E = RI$, $I = R/E$ $R = E/I$
   E. None of the above

5. If a DVOM with an accuracy specification of (1.0% + 2d) shows a reading of 11.5 V, what is the range of possible true voltages?

   A. 11.3 to 11.7
   B. 11.2 to 11.8
   C. 11.1 to 11.9
   D. 11.0 to 12.0
   E. None of the above

6. If a circuit has 3.6 kΩ in series with 8 MΩ and a 16-volt source, how much current will flow through this circuit?

7. A circuit with 14.4 volts in series with the parallel combination of 1 kΩ and 3 kΩ resistors will have what current coming from the voltage source?

8. A circuit has a source voltage pushing 2.5 mA of current through a 3 kΩ resistor in series with the parallel combination of 4 kΩ and 6 kΩ. What is the value of the source voltage?

9. Why should you avoid splicing a copper wire to an aluminum wire?

   A. Galvanic corrosion will result.
   B. The aluminum wire is a poor conductor of electricity.
   C. The copper wire is heavier and more expensive.
   D. The aluminum wire will become too stressed.
   E. None of the above.

10. What is the minimum allowable distance between a splice that you make and other splices, connectors, and branches in the harness?

11. When installing a fusible link, what wire gauge size of fusible link wire should you use to connect with a particular harness wire?

    A. Six wire gauges smaller than the wire harness
    B. Two wire gauges larger than the wire harness
    C. The same wire gauge size as the wire harness
    D. Four wire gauges smaller than the wire harness
    E. None of the above

12. If we triple the number of turns of wire wrapped around an electromagnet, what will happen to the magnetic force?

    A. It will increase.
    B. It will decrease by half.
    C. It will remain the same.
    D. It will become saturated.
    E. None of the above

13. What is the frequency of a sine wave that takes 10 ms to complete 5 cycles or waves?

14. What is the dc equivalent voltage for 18 peak volts, when the amount of work they can do is compared?

15. If one sine wave on the screen of an oscilloscope takes 3.2 horizontal divisions and the Time/Div control is on 2.5 ms per division, what is the frequency of the signal?

16. Two signals on a dual-trace scope each take 3.5 divisions horizontally for one wave and are 0.7 division different at the point they cross the center line. How many degrees are they out of phase?

17. What is the voltage drop across a silicon PN junction?

18. What should the value of a series resistor be to limit the current through a typical LED if the voltage source is 16 volts? Give the calculated value of resistance.

19. A transistor with a beta of 300 will have how much current flowing through the collector with 0.2 mA of current flow through the base?

20. If the transistors in a darlington pair have betas of 200 and 25, what will be the total current gain for the pair?

21. What should the value of the resistance be in the base circuit to protect the base emitter junction of a transistor that will be switching 750 mA with a signal input of 6 volts?

22. What should the emitter resistance be for a switching transistor that will be controlling two LEDs in parallel that require a total of 30 mA? The signal input to the base will be 4 volts.

23. What is the gate current in a MOSFET that is controlling 150 mA of current?

24. A comparator is connected to a supply of 16 volts and ground. It has a fixed 5 volts on the minus input. What will the output voltage be with 3.6 volts on the plus input?

25. A two-input (A and B) AND gate has its output connected to one input of a two-input NOR gate. (Input C is still free.) This gives a total of three inputs to the circuit (A, B, and C). List all of the logic possibilities that will give a logic 1 on the output of this circuit.

Unit D Test

Engine Electrical Systems

---

1. If a battery can deliver 320 amperes at 10.2 volts, what is the power rating of the battery?

2. What is the amp-hour (AH) rating of a battery that delivered 1.20 amperes for 20 hours at room temperature?

3. A battery that is fully charged should have what voltage across its terminals?

4. A battery should be replaced when the specific gravity readings differ between cells. How much of a difference is too much?

5. What should the specific gravity of a fully charged cell in a good battery be?

6. When you look inside a fully charged good battery, what color is the negative plate?

7. A car battery with no load across it has 12.50 volts between its terminals. When a load is placed across the battery, the voltage drop across the 0.4Ω load becomes 12.25 volts. What is the internal resistance of the battery?

8. What three design changes can be made to an alternator to increase its performance?

   A. Use a larger pinion gear, use heavier metal on the case, and run it faster.
   B. Use a larger contact disk, increase the size of the armature, and shorten the plunger stroke.
   C. Increase the speed of rotation, increase the number of turns in the windings, and increase the magnetic force from the rotor.
   D. Use roller bearings, spin the armature slower, and lower the current input.
   E. None of the above

9. What will happen if the contact disk does not release from making contact with the terminals B and M?

   A. The motor will stop running.
   B. The solenoid will burn up.
   C. The motor will run continuously.
   D. The pull-in winding will burn open.
   E. None of the above

10. How would the starter motor behave if the pull-in coil on the solenoid was open?

   A. The starter motor would run backwards.
   B. The solenoid would immediately get hot and probably burn up.
   C. The solenoid would slowly, if at all, pull in, and when it was pulled in, the motor would crank in a normal manner.
   D. The solenoid would vibrate in and out.
   E. None of the above

Unit E Test

Body Electrical Systems

---

1. Which of the following is **not** part of the seven steps to the troubleshooting plan?

   1. Determine the specific complaint.
   2. Demonstrate the problem.
   3. Test all of the potential problem components.
   4. Plan additional tests.
   5. Locate the problem.
   6. Make the repair.
   7. Test the repaired vehicle.

2. What is an A/D converter?

3. How many miles have been traveled if 5,005 pulses have been sent to the stepper motor in an odometer?

4. Arrange the three basic types of memory chips (RAM, ROM, PROM) next to the statement which bests describes them.

   A. Read write memory.
   B. Can be read from only.
   C. Can be programmed in a fixture.

5. The halogen bulb, unlike most ordinary bulbs, is under a positive pressure. Ordinary bulbs have a vacuum inside them. How does this pressure cause them to be more dangerous?

6. What are the two broad catagories for seat belts that you actively put on and belts that automatically wrap around you?

7. What is the minimum speed that will cause the air bags to deploy, when you run into a parked car that is about the same size as your car?

8. What is the length of time that it takes for the air bags to completely inflate from the moment of impact?

9. When should an air bag be replaced?

10. Does the air bag system replace the need for seat belts? Explain.

Unit F Test

Engine Electronic Control Systems

1. If a thermistor that is used for measuring coolant temperature, with a positive temperature coefficient, goes from 120°F to 75°F, what will happen to the resistance of the device?

2. What temperature does an oxygen sensor have to reach before it will start sending valid data?

3. Which input sensor is ignored when the ECA (computer module) is operating "OPEN LOOP"?

4. Which output from the ECA (computer module), in a fuel-injected system, has the greatest effect on the fuel-air ratio?

5. Approximately, what is the fuel pressure in the fuel lines going to the engine?

6. What happens to the data that is received by the computer module from the oxygen sensor when the driver pushes the throttle to the floor?

7. What input sensor is used to control the glow plug system in a diesel car?

8. In a direct ignition system, how many high-voltage pulses per minute will each spark plug receive if the engine is running at 500 rpm?

9. What are the two inputs to a Hall effect switch that are required before the switch will output voltage?

10. What is a Hall effect device made from?

11. If the gasoline and air were combined or burned perfectly in an engine, what are the only two compounds that would be the product of this combustion?

12. Which one of the emission control systems is used to reduce the quantity of nitrogen oxides emitted?

13. What engine condition will generate unburned hydrocarbons?

Unit G Test

Vehicle Control Systems

---

1. What is the lowest speed at which the cruise control will work on most Ford cars?
2. How many output solenoids are in the transaxle of a typical automobile?
3. If the transaxle controller shuts down after receiving data that shows a serious fault with the system, what happens to the transaxle system?
4. How are the six pressure switches on the transaxle solenoid asssembly used?
5. What are the upper and lower limits of wheel slippage that a good antilock brake system will try to hold?
6. How much current is used to control the three-position solenoid valve on the antilock brake system?
7. On the Toyota antilock brake system, how long does the computer pause before it starts repeating the fault codes?
8. After you have completed the repairs on the antilock brake system, how can you clear the fault codes from the computer memory?

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F-2 Engine Fuel Delivery Systems
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WORK SHEET

FOR COORDINATING JOBS WITH RELATED INSTRUCTION USING

AUTOMOTIVE TECHNICIAN II FOR ICT

This form is for your convenience in planning and keeping records of training. Contents of the student's manual are at the left. The columns below provide space for listing job experiences for the individual student and assignment numbers and other references related to each job. Blanks are large and divided by days so the teacher and student can list other information that might be useful in a weekly log.

Student ______________________________

Training Station ______________________________

JOB EXPERIENCES	RELATED INSTRUCTION
Monday Work Hrs:	
Tuesday Work Hrs:	
Wednesday Work Hrs:	
Thursday Work Hrs:	
Friday Work Hrs:	

TX92C004

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CURRICULUM GUIDE

FOR

Automotive Technician II

for ICT

CE 064 918

CURRICULUM GUIDE

FOR

AUTOMOTIVE TECHNICIAN II FOR ICT

By

Troy Notgrass

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COMPLIANCE STATEMENT

TITLE VI, CIVIL RIGHTS ACT OF 1964; THE MODIFIED COURT ORDER, CIVIL ACTION 5281, FEDERAL DISTRICT COURT, EASTERN DISTRICT OF TEXAS, TYLER DIVISION

Reviews of local education agencies pertaining to compliance with Title VI Civil Rights Act of 1964 and with specific requirements of the Modified Court Order, Civil Action No. 5281, Federal District Court, Eastern District of Texas, Tyler Division are conducted periodically by staff representatives of the Texas Education Agency. These reviews cover at least the following policies and practices:

(1) acceptance policies on student transfers from other school districts;

(2) operation of school bus routes or runs on a non-segregated basis;

(3) nondiscrimination in extracurricular activities and the use of school facilities;

(4) nondiscriminatory practices in the hiring, assigning, promoting, paying, demoting, reassigning, or dismissing of faculty and staff members who work with children;

(5) enrollment and assignment of students without discrimination on the basis of race, color, or national origin;

(6) nondiscriminatory practices relating to the use of a student's first language; and

(7) evidence of published procedures for hearing complaints and grievances.

In addition to conducting reviews, the Texas Education Agency staff representatives check complaints of discrimination made by a citizen or citizens residing in a school district where it is alleged discriminatory practices have occurred or are occurring.

Where a violation of Title VI of the Civil Rights Act is found, the findings are reported to the Office for Civil Rights, Department of Health, Education and Welfare.

If there is a direct violation of the Court Order in Civil Action No. 5281 that cannot be cleared through negotiation, the sanctions required by the Court Order are applied.

TITLE VII, CIVIL RIGHTS ACT OF 1964: EXECUTIVE ORDERS 11246 and 11375; TITLE IX 1973 EDUCATION AMENDMENTS: REHABILITATION ACT OF 1973 AS AMENDED; 1974 AMENDMENTS TO THE WAGE-HOUR LAW EXPANDING THE AGE DISCRIMINATION IN EMPLOYMENT ACT OF 1967; VIETNAM ERA VETERANS READJUSTMENT ASSISTANCE ACT OF 1972 AS AMENDED IN 1974.

It is the policy of the Texas Education Agency to comply fully with the nondiscrimination provisions of all federal and state laws and regulation by assuring that no person shall be excluded from consideration for recruitment, selection, appointment, training, promotion, retention, or any other personnel action, or be denied any benefits or participation in any programs of activities which it operates on the grounds of race, religion, color, national origin, sex, handicap, age, or veteran status (except where age, sex, or handicap constitute a bona fide occupational qualification necessary to proper and efficient administration). The Texas Education Agency makes positive efforts to employ and advance in employment all protected groups.

How to Use the Curriculum Guide for Automotive Technician II

Automotive Technician II for ICT is an occupationally specific course for students in grades 12. It is the second of a two-year course which will provide students with basic skills associated with automotive technicians. It is designed as a one-hour, one-year (180 classroom hours–2 credits) course with appropriate training at an approved cooperative training station.

Organization and Design

Material in this guide may be used in either of two ways. First, it may be used to help the instructor develop a study guide for the student. In this instance, the student's manual could serve as the text. Other useful information for the instructor are the lists of required laboratory supplies, essential elements common to all trade and industrial courses, essential elements for automotive technician courses, and assignments titles with objectives and essential elements covered in that assignment.

Or, these prepared student's manuals and instructor's guides may be purchased from:

The University of Texas at Austin
Educational Resources
Extension Instruction and Materials Center
P.O. Box 7218
Austin, Texas 78713-7812

The instructor's guide is designed to help the instructor make certain that each student gets the most benefit possible out of both the student's manual and experiences at the training station. It provides answers to assignment exercise, laboratory experiments or workbook activities, the unit tests, and a worksheet to help in coordinating work experiences with the assignments.

The instructor should keep all answers to questions. The actual unit tests can be removed to make them easier to use or reproduce. For greater convenience, the instructor's guide is punched for notebook use and held together by staples only.

A basic skills application matrix is also included to show the correlation between selected language arts, mathematics, science, and social studies essential elements and trade and industrial essential elements. Five essential elements were selected from the 32 courses offered in language arts, five from the 22 courses offered in mathematics, five from the 18 courses offered in science, and five from the 11 courses offered in social studies.

The student's self-contained manual is designed for use in presenting related technical information to (1) groups of trade and industrial students with a variety of vocational objectives and (2) homogeneous groups in which the learning levels of individual students vary considerably. The manual is not intended to be used as a type of correspondence course, but must be used by students under the direct supervision of an instructor.

Required Laboratory Supplies

The following supplies are necessary for the student to work the laboratory experiments. Working the laboratory experiments will not endanger the student or others in the classroom if the directions in the experiments are followed. No high voltages are required nor are acids used. Approximately $50.00 is required to purchase these supplies at a Radio Shack or other electronics supplier.

Parts List:

1	battery holder for four dry cell batteries (AAA is sufficient)
4	dry cell batteries
1	package of 10 jumper leads with alligator clips
1	DMM (Digital Multimeter)
7	feet of insulated light-duty wire
6	clips (the clips should match the wire size)
1	roll of electrical tape
1	crimping tool (must include features to cut wire and strip insulation)
3	nails approximately 2 inches long
1	100 µF or higher capacitor
4	silicon diodes
1	light-emitting diode (LED)
1	comparator
1	socket for the comparator
1	variable resistor (10 kΩ potentiometer)
	Miscellaneous paper, wooden pencil, or other stick for a pointer
1	47 Ω resistor
1	120 Ω resistor
1	220 Ω resistor
1	330 Ω 5% 1/4 watt resistor
1	470 Ω 5% resistor
1	680 Ω resistor
1	1 kΩ resistor
1	2.2 kΩ 5% resistor
1	4.7 kΩ 5% resistor
1	9 kΩ 5% resistor
1	10 kΩ resistor

Academic Background Required

Students must have the correct background in order to succeed in this field.

English. Students should have a good background in English. They should be able to read at the eleventh-grade level in order to understand the schematics, specifications, etc.

Mathematics. The student should have a good background in mathematics. Successful completion of two years of algebra is desirable.

Science. Background courses in chemistry and physics are beneficial to automotive electronic technicians.

Aptitudes. Students should have a high mechanical aptitude and a high degree of manual dexterity.

This information may be used in counseling students who express a desire to train in this field. It also could be useful to school counselors who may have the opportunity to guide students toward a vocational program.

Content Development

Automotive Technician II for ICT is designed as a self-study text which does not rely upon a knowledgeable instructor and requires a laboratory. The student's manual is organized to guide the student from the fundamentals of electricity and electronics to the basic design of electric and electronic sensors and actuators to the application of sensors and actuators in the body electrical system, engine control systems, and vehicle control systems. Each assignment in the unit on fundamentals (Unit C) builds on the knowledge students have gained from the previous assignments. The assignments are developed sequentially. Therefore, students should study the assignments in this unit in order. All succeeding assignments may be studied in any order. When they have completed this course, they will be adquately prepared to enroll in an automotive technician's course at the postsecondary level or to continue in the occupation as an automotive technician.

Organization

The student's manual is designed to use as many fundamental teaching principles as possible. Each part of the manual is based on one of these principles.

Objectives. The first fundamental teaching principle is that the student should be *informed* at the outset what should be learned in the assignment. This is done through a statement of objectives at the beginning of each assignment. These are performance objectives that can be tested on completion of the assignment.

Technical information. The second teaching principle is that technical information should be presented in *complete, but concise form.* This information is presented step-by-step, going from the simple to the complex, from the known to the unknown, thus making learning easy. Of the four teaching principles discussed here, this is by far the most important. The biggest favor you can do for the student is to persuade her or him that, if she or he learns the information presented, the grades will take care of themselves.

Laboratory experiments and workbook activities. The third teaching principle is that technical information is better learned if it can be *applied* as soon as possible after presentation. The laboratory experiments and workbook activities are designed to cause the student to use higher thinking skills such as analyzing and forming conclusions by using the technical information studied in the assignment.

Exercise. Another method of applying the information is through exercise questions for each assignment. The questions are phrased to emphasize key points, to aid in learning facts that must be memorized, or to provoke thought about and evaluation of the technical information. You should emphasize to students that both the objectives and the technical information should be read before any attempt is made to answer questions in the exercise. Answers may also be useful when helping a student who is having difficulty with an assignment exercise. The student's answers need not be stated in exactly the same words used in the assignment information.

Tests. A fourth teaching principle is carried out in the instructor's guide. The principle is that the effectiveness of the assignment should be *evaluated.* This is done through a unit test that is keyed to the objectives stated for the assignments within each unit. These tests should be given on completion of the unit. Answers to tests provide a reference for grading. *You should retain all answers for obvious reasons.*

Tests and Work Sheet

The last section of this instructor's guide has been placed after a divider page so that the unit tests and the work sheet can be removed for use with individual students or for reproduction. You may reproduce these pages *without permission.*

The work sheet is provided for your convenience in (1) planning how job experience is to be matched to related instruction in the student's manual and (2) keeping daily records as the student progresses through the year. The assignments are coded and can be easily listed opposite the desired jobs. Also, space is provided for other records you may wish to include on the work sheet.

Instructional Key

Assignment	Title	Essential Elements
A:	**Introduction**	
A-1	How to Use This Manual	
A-2	Occupational Outlook	(a)(2)(A)
A-3	Owning Your Own Business	(a)(3)(A–D)
B:	**Shop Safety and Tools**	
B-1	Shop Safety	(a)(4)
B-2	Hand Tools	(a)(7)(D)
B-3	Measuring Tools	(a)(7)(D)
B-4	Power Tools and Equipment	(a)(7)(D)
C:	**Basic Electricity and Electronics**	
C-1	Fundamentals of Electricity	(gg)(1–3)
C-2	Circuit Analysis	(gg)(1-3)
C-3	Conductors and Resistors	(gg)(1-3)
C-4	Magnetism	(gg)(1–3)
C-5	Schematics (Electrical Road Maps)	(gg)(1–3)
C-6	AC and Computer Signals	(gg)(1–3)
C-7	Semiconductor Diodes	(gg)(1–3)
C-8	Transistors	(gg)(1–3)
C-9	Computer Circuits	(gg)(1–3)

D:	**Engine Electrical Systems**	
D-1	The Battery	(gg)(1-4)
D-2	The Charging System	(gg)(1-4)
D-3	The Cranking System	(gg)(1-4)
E:	**Body Electrical Systems**	
E-1	Body Lights, Switches, and Related Systems	(gg)(1, 2, & 4)
E-2	Instrument Panel	(gg)(1–4)
E-3	Vehicle Restraint Systems	(gg)(1, 2, & 4)
F:	**Engine Electronic Control Systems**	
F-1	Automotive Sensors	(gg)(1, 2, & 4)
F-2	Engine Fuel Delivery Systems	(gg)(1, 2, 4, & 5)
F-3	Ignition Systems	(gg)(1, 2, 4, & 5)
F-4	Emission Control Systems	(gg)(1, 2, 4, & 5)
G:	**Vehicle Control Systems**	
G-1	Cruise Control	(gg)(1, 2, & 4)
G-2	Electronic Gearshift Transmissions	(gg)(1, 2, & 4)
G-3	Antilock Brake Systems	(gg)(1, 2, & 4)

Essential Elements Common to All Trade and Industrial Courses

§75.88 Trade and Industrial Education

(a) The elements in this subsection are common to all trade and industrial courses unless otherwise indicated and shall be included in each course at the appropriate level. They are described here to preclude repetitions in each course. Every school offering trade and industrial education shall provide courses which include the following essential elements:

(1) *Leadership* concepts and skills. The student shall be provided opportunities to:

- (A) demonstrate skills, characteristics, and responsibilities of leaders and effective group members;
- (B) demonstrate a knowledge of parliamentary procedure principles;
- (C) plan and conduct leadership activities; and
- (D) prepare for effective citizenship and for participation in our democratic society.

(2) Concepts and skills related to successful *employment and/or postsecondary training*. The student shall be provided opportunities to:

- (A) identify employment opportunities and preparation requirements in chosen fields;
- (B) identify effective methods to secure and terminate employment;
- (C) demonstrate effective communication skills both oral and written and follow through on assigned tasks;
- (D) demonstrate dependability and punctuality;
- (E) demonstrate productive work habits and attitudes;
- (F) understand the importance of taking pride in the quality of work performed;
- (G) recognize the dignity in work;
- (H) develop skills in planning and organizing work;
- (I) apply required methods and sequences when performing tasks;
- (J) apply principles of time management and work simplification when performing assigned tasks;
- (K) identify ethical practices and responsibilities; and
- (L) understand the importance of the application of organizational policies and procedures.

(3) Concepts and skills associated with *entrepreneurship*. The student shall be provided opportunities to:

- (A) identify opportunities for business ownership;
- (B) understand the risk and profit motive factor;

(C) understand the elements and advantages of the free enterprise system; and
(D) explain the role of small business in the free enterprise system.

(4) Concepts and skills related to *safety and safe working conditions.* The student shall be provided opportunities to identify and apply safe working practices to all training situations.

(5) Concepts and skills associated with *human relations and personality development.* The student shall be provided opportunities to:

(A) understand the importance of maintaining good health and proper appearance for effective job performance;
(B) understand oneself and others;
(C) exercise self-control;
(D) accept and use criticism;
(E) recognize basic human relationships as they relate to business success; and
(F) demonstrate characteristics for successful working relationships.

(6) Concepts and skills related to *personal and business management.* The student shall be provided opportunities to:

(A) explain how management assists in reaching personal and family goals;
(B) explain the management process;
(C) describe the role of management in controlling stress;
(D) identify and understand personal checking accounts;
(E) identify and understand personal loan application processes;
(F) identify and understand different financial institutions;
(G) identify the role and functions of business management;
(H) understand the lines of authority; and
(I) identify effective supervisory techniques.

(7) Concepts and skills associated with the *specific occupation* being taught. The student shall be provided opportunities to:

(A) understand the basic concepts of and develop proficiency in the occupational area for which instruction/training is provided;
(B) develop a fundamental understanding of mathematical principles and scientific procedures;
(C) understand terminology utilized;
(D) identify tools, equipment, and materials used; and
(E) develop and demonstrate appropriate techniques for the selection, use, maintenance, and storage of tools, equipment, and materials.

Essential Elements for Automotive Technician

(gg) *Automotive technician* (2-3 units) shall include the essential trade and industrial elements and concepts associated with automobile mechanics. The student shall be provided opportunities to:

(1) understand the functions of and analyze malfunctions in the automobile components;
(2) read and interpret appropriate repair and labor manuals;
(3) understand the basic fundamentals of the automobile engine and repair internal systems;
(4) understand, service, repair, and/or replace carbureted fuel systems, engine cooling systems, emission control systems, electrical and electronic equipment, power trains, chassis, and heating and air-conditioning systems; and
(5) understand the fundamentals of gasoline fuel injection and diesel engine fuel injection systems.

Basic Skills Applications

Language Arts E.E. §75.61	(a)(4)(C)	(a)(4)(I)	(b)(4)(C)	(b)(4)(G)	(c)(4)(D)
Assignment Number	C-6	C-7	C-9	C-2	C-7
Mathematics E.E. §75.63	(c)(1)(B)	(c)(3)(C)	(c)(4)(C)	(e)(2)(F)	(e)(3)(C)
Assignment Number	C-2	C-7	C-1	C-1	C-7
Science E.E. §75.64	(b)(7)(C)	(c)(7)(B)	(d)(2)(C)	(m)(2)(B)	(p)(2)(A)
Assignment Number	C-2	C-4	F-4	C-8	C-1
Social Studies E.E. §75.68	(b)(3)(D)	(c)(5)(L)	(d)(4)(E)	(k)(2)(B)	(k)(3)(A)
Assignment Number	A-3	A-3	F-4	C-2	F-3

Language Arts E.E.	**75.61**
(a)(4)(C)	Expand vocabulary
(a)(4)(I)	Draw conclusions and make inferences
(b)(4)(C)	Recognize relevant details
(b)(4)(G)	Evaluate and make judgments
(c)(4)(D)	Perceive cause and effect relationships

Mathematics E.E.	**75.63**
(c)(1)(B)	Use scientific notation
(c)(3)(C)	Find percent and percentage
(c)(4)(C)	Use metric and customary units
(e)(2)(F)	Use formulas to solve problems
(e)(3)(C)	Identify and graph functions

Science E.E.	**75.64**
(b)(7)(C)	Compare atomic structures of simple elements
(c)(7)(B)	Compare the functions of electronic circuits
(d)(2)(C)	Explore magnetic and electrical interactions
(m)(2)(B)	Examine environmental science principles
(p)(2)(A)	Organize thought processes to accomplish goals (applications of electronics, photography)

Social Studies E. E.	**75.68**
(b)(3)(D)	Explain the development and importance of new business and labor organizations
(c)(5)(L)	Explain the positive aspects and effects of American capitalism upon the world
(d)(4)(E)	Analyze environmental issues associated with urban growth
(k)(2)(B)	Apply the strategies of problem solving
(k)(3)(A)	Draw inferences from data

Assignment Titles, Objectives, and Related Essential Elements

Unit A: Introduction

Unit Objectives: *After completing this instructional unit, you will be able to:*
- *explain the organization and use of this manual*
- *explain the nature and outlook of the automotive technician's field*
- *explain the procedures for establishing your own business*

A-1: How to Use This Manual

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain the author's first concern in writing this manual*
- *list the four parts of each assignment*
- *state the purpose of the objectives*
- *explain the proper sequence of study for each assignment*
- *explain why the test should be a snap*

A-2: Occupational Outlook

Essential Elements: (a)(2)(A)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain where most automotive technicians are employed*
- *explain where the best training background for trainees is obtained*
- *explain who furnishes the tools and equipment in a shop*
- *explain the average working hours for most technicians*
- *explain the outlook for automotive technicians through the year 2000*

A-3: Owning Your Own Business

Essential Elements: (a)(3)(A-D)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain how to select a location for a business*
- *explain how to raise the capital necessary to start up a business*
- *explain three methods of organizing a business*
- *explain the various types of business records that must be maintained*
- *explain some of the tried methods of hiring and keeping good automotive technicians*

Unit B: Shop and Tools

Unit Objectives: *After completing this instructional unit, you will be able to:*
- *explain the safety practices required of an automotive technician*
- *explain the tools and equipment used in an automobile repair shop*

B-1: Shop Safety

Essential Elements: (a)(4)

Specific Objectives: *After completing this assignment, you will be able to:*
- *name the primary cause of accidents*
- *explain how horseplay should be dealt with*
- *explain why loose clothing should not be worn in the shop*
- *explain why precision tools should be stored in a clean and safe cabinet*

B-2: Hand Tools

Essential Elements: (a)(7)(D)

Specific Objectives: *After completing this assignment, you will be able to:*
- *describe the hand tools discussed in this assignment*
- *explain the purposes and uses of the hand tools discussed*

B-3: Measuring Tools

Essential Elements: (a)(7)(D)

Specific Objectives: *After completing this assignment, you will be able to:*
- *name the parts of a micrometer*
- *explain how to hold a micrometer when using it*
- *explain how to read a micrometer*
- *describe the measuring tools discussed*
- *explain how to use the tools discussed*

B-4: Power Tools and Equipment

Essential Elements: (a)(7)(D)

Specific Objectives: *After completing this assignment, you will be able to:*
- *list the most commonly used power tools and equipment in automotive service*
- *describe the use of power tools and equipment*
- *compare the advantages of electric, pneumatic, and hydraulic tools*
- *list safety precautions to observe when using power tools*

Unit C: Basic Electricity and Electronics

Unit Objectives: *After completing this instructional unit, you will be able to explain the fundamentals of:*

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

C-1: Fundamentals of Electricity

Essential Elements: (gg)(1-3)

Specific Objectives: *After completing this assignment, you will be able to:*

- *explain the difference between a conductor and an insulator*
- *use Ohm's law to calculate the voltage*
- *use Ohm's law to calculate the current*
- *use Ohm's law to calculate the resistance*
- *explain the difference between conventional current flow and electron flow*

C-2: Circuit Analysis

Essential Elements: (gg)(1-3)

Specific Objectives: *After completing this assignment, you will be able to:*

- *explain the difference between series and parallel circuits*
- *explain how to use a digital meter*

C-3: Conductors and Resistors

Essential Elements: (gg)(1-3)

Specific Objectives: *After completing this assignment, you will be able to:*

- *read the resistance of color-coded resistors*
- *explain how to repair damaged wire*
- *explain how to repair connectors*

C-4: Magnetism

Essential Elements: (gg)(1-3)

Specific Objectives:
After completing this assignment, you will be able to:

- *explain how magnetism works*
- *build an electromagnet*
- *explain how a solenoid works*

C-5: Schematics (Electrical Road Maps)

Essential Elements: (gg)(1-3)

Specific Objectives: *After completing this assignment, you will be able to:*

- *read and understand automotive electrical drawings*
- *explain the use of good troubleshooting practices*

C-6: AC and Computer Signals

Essential Elements: (gg)(1-3)

Specific Objectives: *After completing this assignment, you will be able to:*

- *explain how to use an oscilloscope to measure the frequency and voltage level of a signal*
- *explain how a capacitor works in a circuit*
- *explain what an ac signal is and how it is made by the alternator*

C-7: Semiconductor Diodes

Essential Elements: (gg)(1-3)

Specific Objectives: *After completing this assignment, you will be able to:*

- *explain how diodes operate*
- *explain electronic components*
- *explain wire and connector repair*

C-8: Transistors

Essential Elements: (gg)(1-3)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain how diodes operate*
- *explain how to use transistors as a switch*
- *explain the difference between bipolar and FET transistors*

C-9: Computer Circuits

Essential Elements: (gg)(1-3)

Specific Objectives: *After completing this assignment, you will be able to:*
- *convert from the binary numbering system to hexadecimal*
- *determine the output of a logic gate with various inputs*
- *demonstrate a knowledge of flip-flops and simple memory devices*

Unit D: Engine Electrical Systems

Unit Objectives: *After completing this instructional unit, you will be able to explain the functions of:*
- *automotive batteries*
- *charging systems*
- *engine starting systems*

D-1: The Battery

Essential Elements: (gg)(1-4)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain how to test a lead acid car battery*
- *explain how to charge and maintain a lead acid car battery*
- *calculate the internal resistance of a car battery*

D-2: The Charging System

Essential Elements: (gg)(1-4)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain how to test the alternator on a car*
- *explain how to test the charging system*
- *explain how to repair the alternator*

D-3: The Cranking System

Essential Elements: (gg)(1-4)

Specific Objectives:
After completing this assignment, you will be able to:
- *explain the procedures for troubleshooting the starter motor on a car*
- *explain the procedures for troubleshooting the engine starting system*

Unit E: Body Electrical Systems

Unit Objectives:
After completing this instructional unit, you will be able to explain the operations of:
- *lights and switches system and related systems on a typical car*
- *automotive instrument panel*
- *active and passive restraint systems*

E-1: Body Lights, Switches, and Related Systems

Essential Elements: (gg)(1, 2, and 4)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain the procedures for troubleshooting problems in the headlight and taillight circuits*
- *explain the procedures for using the troubleshooting plan*

E-2: Instrument Panel

Essential Elements: (gg)(1-4)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain the procedures for troubleshooting an LCD instrument panel*
- *explain the difference between LCD, LED, and VFD instrument panels*

E-3: Vehicle Restraint Systems

Essential Elements: (gg)(1, 2, and 4)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain how to service a passive seat belt system*
- *explain how to service an air bag restraint system*

Unit F: Engine Electronic Control Systems

Unit Objectives: *After completing this instructional unit, you will be able to explain the fundamental operation of each of the following:*
- *automotive sensors*
- *the fuel delivery system*
- *the electronic ignition system*
- *the emission control system*
- *the diesel fuel delivery and control system*

F-1: Automotive Sensors

Essential Elements: (gg)(1, 2, and 4)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain how the various sensors on the automobile operate*
- *explain how the voltage divider method is used to provide a signal to the computer from a sensor*

F-2: Engine Fuel Delivery Systems

Essential Elements: (gg)(1, 2, 4, and 5)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain how the computer controls the delivery of fuel to the injectors*
- *explain how the computer learns and corrects for changes in the engine*

F-3: Ignition Systems

Essential Elements: (gg)(1, 2, 4, and 5)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain how a sensor tells the direct ignition system which companion pair of spark plugs to fire*
- *explain how the Hall effect switch is used as a sensor to detect the position of the crankshaft and cam*

F-4: Emission Control Systems

Essential Elements: (gg)(1, 2, 4, and 5)

Specific Objectives: *After completing this assignment, you will be able to:*
- *explain how harmful emissions are controlled*
- *explain the importance of the input sensors in controlling harmful emissions*

Unit G: Vehicle Control Systems

***Unit Objectives:** After completing this instructional unit, you will be able to explain the fundamentals of:*

- *electricity*
- *cruise control on a typical automobile.*
- *the electronic controls on an automatic transmission.*
- *the electronic controls on the braking system in a typical automobile*

G-1: Cruise Control

Essential Elements: (gg)(1, 2, and 4)

***Specific Objectives:** After completing this assignment, you will be able to:*

- *understand how a typical speed control system controls the vehicle speed*
- *understand where the speed control system obtains its input data*

G-2: Electronic Gearshift Transmissions

Essential Elements: (gg)(1, 2, and 4)

***Specific Objectives:** After completing this assignment, you will be able to:*

- *explain how the computer module controls the shift points on a typical transaxle*
- *explain how problems affect the operation of the transaxle*

G-3: Antilock Brake Systems

Essential Elements: (gg)(1, 2, and 4)

***Specific Objectives:** After completing this assignment, you will be able to:*

- *understand how the computer module controls the application of braking force*
- *understand how the computer module receives the information necessary to make decisions resulting in control of the brakes*

References

Troy Notgrass, *Automotive Technician II for ICT*, Instructor's Guide, The University of Texas at Austin, Extension Instruction and Materials Center, P.O. Box 7218, Austin, Texas 78713-7218

Troy Notgrass, *Automotive Technician II for ICT*, Student's Manual, The University of Texas at Austin, Extension Instruction and Materials Center, P.O. Box 7218, Austin, Texas 78713-7218

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Automotive Technician II for ICT

Student's Manual

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Prepared by

Troy Notgrass
and
Bob Snider

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Director, Educational Resources / Barbara E. Selke-Kern, Ph.D.
Production Coordinator / Barbara Sutherland
Artist / Debra Dionisio
Publishing Technician / Kathryn N. Roberts
Editor / Barbara Sutherland

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512-471-7716 or 1-800-252-3461 (within Texas)
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Foreword

This publication is one of a series of self-contained instructional materials for trade and industrial students. Each student who uses this material can work at his or her own pace, learning those things that best fit her or his specific needs. The design of the material makes it possible to relate work experience on the job to information studied at school.

Although the material is individualized, it should be used under the supervision of an instructor. For that reason, two basic publications are offered, a student's manual and an instructor's guide.

The **student's manual** is for the use of the person in training. Each unit includes appropriate information, objectives to be met, and exercise questions that help the student meet those objectives.

The **instructor's guide** provides information to the instructor on how to use the material to the best advantage of the student, answers to exercise questions and unit test questions, one set of unit tests, and a work sheet.

Every effort has been made to produce a publication that addresses the unique needs of our current student population. Students with limited English proficiency (LEP), as well as handicapped, educationally disadvantaged, and nontraditional students, may require modification of the material in this publication. The professional staff of EIMC will gladly work with any instructor having these students to how how the instructional material can be adapted for specific individualized instruction. Consult local, state, and federal agencies that offer assistance and guidance and that can provide sound recommendations for productive classroom management.

Kathryn R. Allen, Ph.D.
Director, Extension Instruction
and Materials Center

Preface

The modern automobile has become very efficient and economical to operate as result of extensive use of electronics. Although the electronics used in automobiles is very reliable, some problems still occur and some of the parts do wear out. This manual has been written to prepare the future automotive technician with some of the electronic skills they will need to service these automobiles.

Unit C was written to provide the student with the basics in electrical and electronic theory. It should be studied in the sequence in which it was written. The student should have a good grasp of Unit C material before trying to cover any of the following sections. The lessons in the following sections can be studied in any order after completing Unit C.

Since the automotive technician will rarely deal with a printed circuit board, the laboratory part of the lessons was designed using jumper wires instead of a breadboard. The students' retention and confidence in the lesson material will be improved when they complete the laboratory or workbook portion of the lessons.

Although much of the automotive electronics used today is on the cutting edge of technology, the authors feel that the material in Unit C is adequate for a beginning automotive technician. The successful completion of this material will help in providing a more secure and profitable position for the new automotive technician.

Acknowledgments

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COMPLIANCE STATEMENT

TITLE VI, CIVIL RIGHTS ACT OF 1964; THE MODIFIED COURT ORDER, CIVIL ACTION 5281, FEDERAL DISTRICT COURT, EASTERN DISTRICT OF TEXAS, TYLER DIVISION

Reviews of local education agencies pertaining to compliance with Title VI Civil Rights Act of 1964 and with specific requirements of the Modified Court Order, Civil Action No. 5281, Federal District Court, Eastern District of Texas, Tyler Division are conducted periodically by staff representatives of the Texas Education Agency. These reviews cover at least the following policies and practices:

(1) acceptance policies on student transfers from other school districts;

(2) operation of school bus routes or runs on a non-segregated basis;

(3) nondiscrimination in extracurricular activities and the use of school facilities;

(4) nondiscriminatory practices in the hiring, assigning, promoting, paying, demoting, reassigning, or dismissing of faculty and staff members who work with children;

(5) enrollment and assignment of students without discrimination on the basis of race, color, or national origin;

(6) nondiscriminatory practices relating to the use of a student's first language; and

(7) evidence of published procedures for hearing complaints and grievances.

In addition to conducting reviews, the Texas Education Agency staff representatives check complaints of discrimination made by a citizen or citizens residing in a school district where it is alleged discriminatory practices have occurred or are occurring.

Where a violation of Title VI of the Civil Rights Act is found, the findings are reported to the Office for Civil Rights, Department of Health, Education and Welfare.

If there is a direct violation of the Court Order in Civil Action No. 5281 that cannot be cleared through negotiation, the sanctions required by the Court Order are applied.

TITLE VII, CIVIL RIGHTS ACT OF 1964: EXECUTIVE ORDERS 11246 and 11375; TITLE IX 1973 EDUCATION AMENDMENTS; REHABILITATION ACT OF 1973 AS AMENDED; 1974 AMENDMENTS TO THE WAGE-HOUR LAW EXPANDING THE AGE DISCRIMINATION IN EMPLOYMENT ACT OF 1967; VIETNAM ERA VETERANS READJUSTMENT ASSISTANCE ACT OF 1972 AS AMENDED IN 1974.

It is the policy of the Texas Education Agency to comply fully with the nondiscrimination provisions of all federal and state laws and regulation by assuring that no person shall be excluded from consideration for recruitment, selection, appointment, training, promotion, retention, or any other personnel action, or be denied any benefits or participation in any programs of activities which it operates on the grounds of race, religion, color, national origin, sex, handicap, age, or veteran status (except where age, sex, or handicap constitute a bona fide occupational qualification necessary to proper and efficient administration). The Texas Education Agency makes positive efforts to employ and advance in employment all protected groups.

Unit

A

Introduction

A-1 How to Use This Manual
A-2 Occupational Outlook
A-3 Owning Your Own Business

A-1

How to Use This Manual

Unit Objectives:

After completing this instructional unit, you will be able to:

- *explain the organization and use of this manual*
- *explain the nature and outlook of the automotive technician's field*
- *explain the procedures for establishing your own business*

Specific Objectives: *After completing this assignment, you will be able to:*

- *explain the author's first concern in writing this manual*
- *list the four parts of each assignment*
- *state the purpose of the objectives*
- *explain the proper sequence of study for each assignment*
- *explain why the test should be a snap*

You, the student, might be surprised if you knew how closely your interest in this manual and that of the author compare. For instance, did you know that the author's first concern was to make learning as easy as possible? In fact, the organization of this manual has been based on how to make the information in each assignment easy to learn and yet stay in your mind. Each assignment has four parts: (1) the learning *objectives* of the assignment, (2) the *technical information*, (3) the *exercise*, and (4) the *test*. When studied in this order, this arrangement should provide you with the greatest learning opportunity.

To illustrate, go back—right now—and reread the objectives. Had you really paid any attention to the objectives the first time you read them? Or did you even read them? They are important since they tell you what you should be able to remember after completing this assignment. You read the objectives so you will know what important information to look for. Then, as you read, things you need to know will pop up in your mind. A unit test has been written for each unit. The questions test the very information the objectives said was important to learn.

Be sure to read the objectives first, the technical information second, and then answer the questions in the exercise. This arrangement has a purpose. First, you learn what to look for when reading. Then you read and learn all the information required for mastering the lesson. The only reason for the open-book-type exercise is to guide your mind for a third time over the facts considered important. This drill ingrains the information in your mind. If you are in a co-op class, your notebook should show anyone what you have studied during the one or two years you have been in the program. Since this is true, the following rules may be useful in answering the exercise questions. (Of course, your teacher-coordinator may have his or her own rules. If such is the case, by all means follow them.)

1. All work should be done on regular two-, three-, or five-hole loose-leaf paper—never on spiral notebook paper.
2. Either (a) write the answers in complete sentences or (b) write the questions and then write only the answers on the line below.
3. VICA members are supposed to do their work in their own handwriting if it is to be entered in competition.
4. For your own benefit, include a correction sheet in your notebook. You can write down the correct answers after the exercises have been checked by your teacher-coordinator.

A word of caution in working the exercises: *Do not hurry through the questions.* Take your time and learn each assignment as you go. Your teacher-coordinator is not interested in *how many assignments you turn in.* His or her main concern is *how much you have learned.* Just stay busy, do your work, and let the number turned in take care of itself. A further word of caution: Study the assignments within a unit in their numerical order. Each assignment is basic to understanding the following assignments within a unit.

If you study each assignment as instructed here, the fourth part—the test—will be a snap. That is because you will have covered the information three times before taking the test. The test is based on information stated in the objectives. If you do not do well on the test, go back to the objectives, and study the assignment again. After reading the objectives and the technical information and completing the exercise, ask your teacher-coordinator to retest your knowledge. If you still do not do well, perhaps the author should redo the assignment! This goes back to the statement that your interest in this manual is the same as that of the author. You see, if you fail to learn, the author, through his manual, has failed to teach.

Exercise

1. How does your interest in this manual and that of the author compare?
2. List the four parts of each assignment that are designed to make learning easy.
3. What makes the objectives important?
4. Of what secondary importance are the objectives?
5. Give the proper sequence or order of study so that you can learn the most from an assignment.
6. What is the purpose of studying the assignment in the proper sequence?
7. Why is the kind of paper you use and the way you answer questions of importance?
8. If your teacher-coordinator is not particularly interested in how many assignments you turn in, about what is he or she concerned?

9. Why should the test be a snap?

10. Explain how the success or failure of the author depends on how well you do.

A-2

Occupational Outlook

Essential Elements: (a)(2)(A)

Unit Objectives:

After completing this instructional unit, you will be able to:

- *explain the organization and use of this manual*
- *explain the nature and outlook of the automotive technician's field*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain where most automotive technicians are employed*
- *explain where the best training background for trainees is obtained*
- *explain who furnishes the tools and equipment in a shop*
- *explain the average working hours for most technicians*
- *explain the outlook for automotive technicians through the year 2000*

Nature of the Work

Automotive technicians repair and service automobiles and occasionally light trucks. The ability to quickly and accurately diagnose the source of the problem requires good reasoning ability and a thorough knowledge of automobiles. Technicians use a variety of tools in their work. They use power tools such as pneumatic wrenches, machine tools such as lathes and grinding machines, welding tools and cutting equipment, and hand tools.

Technicians in larger shops increasingly specialize. For example, *automatic transmission specialists* work on gear trains, couplings, hydraulic pumps, and other parts of automatic transmissions. *Tune-up specialists* adjust ignition timing and valves, and adjust or replace spark plugs and other parts. They also use electronic test equipment to help them locate malfunctions in fuel, ignition, and emission control systems. wheels

Automotive air-conditioning specialists install and repair air conditioners and service components such as compressors and condensers. *Front-end specialists* align and balance

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The information in this assignment is taken from *Occupational Outlook Handbook, 1988-1989 Edition* (Washington D.C.: Bureau of Labor Statistics, U.S. Department of Labor, April 1988), pp. 393-95.

and repair steering mechanisms and suspension systems. They often use special alignment equipment and wheel balancing machines. *Brake specialists* adjust brakes, replace brake linings and pads, repair hydraulic cylinders, turn discs and drums, and make other repairs on brake systems.

Working Conditions

Generally, automotive technicians work indoors. Most repair shops are well ventilated and lighted, but some are drafty and noisy. Technicians frequently work with dirty and greasy parts, and in awkward positions. They often must lift heavy parts and tools. Minor cuts, burns, and bruises are common, but serious accidents may be avoided when the shop is kept clean and orderly and safety practices are observed.

Employment

Automotive technicians held about 748,000 jobs in 1988. They primarily worked for automotive dealers, automotive repair shops, gasoline service stations, and automotive service facilities at department, automotive, and home supply stores. Others were employed by federal, state, and local governments, taxicab and automobile leasing companies, and other organizations that repair their own fleets of vehicles. Motor vehicle manufacturers employed some technicians to adjust and repair vehicles at the end of assembly lines. Over 20 percent of automotive technicians were self-employed.

Training, Other Qualifications, and Advancement

Most automotive technicians learn the trade by assisting and working with experienced technicians. However, automotive technology is rapidly increasing in sophistication, and most training authorities recommend that persons seeking trainee automotive technician jobs complete a formal training program. Programs for automotive technicians are offered in high schools, community colleges, and public and private vocational and technical schools. Postsecondary automotive technician training programs vary greatly in format. Some concentrate the instruction in only 6 months or a year, depending on how many hours the student must attend each week. Community college programs sometimes spread the training over 2 years, supplement the automotive training with instruction in academic subjects, and award an associate degree.

Knowledge of electronics is increasingly desirable for automotive technicians because electronics are being used in a growing variety of automotive components. Engine controls and dashboard instruments were among the first components to use electronics, but now electronics are being used in brakes, transmissions, steering systems, and a variety of other components. In the past, electrical or electronics problems were usually handled by a specialist, but electronics are becoming so commonplace that most automotive technicians must be familiar with at least the basic principles of electronics in order to recognize when an electronic malfunction may be responsible for a problem, and to be able to test and replace electronic components.

For trainee technician jobs, employers look for people with good reading and basic mathematics skills who can study technical manuals to keep abreast of new technology and learn new service and repair procedures and specifications. Trainees also must possess mechanical aptitude and a knowledge of how automobiles work. Many employers regard the successful completion of a vocational training program in automobile mechanics, either in high school or later at a postsecondary institution, as the best preparation for trainee positions. Experience working on motor vehicles in the Armed Forces or as a hobby is also valuable. Completion of high school is required by a growing number of employers. Courses in automotive repair, electronics, physics, chemistry, and mathematics can provide a good basic educational background for a career as an automotive technician.

Technicians usually buy their hand tools, and beginners are expected to accumulate tools as they gain experience. Many experienced technicians have thousands of dollars invested in tools. Employers furnish power tools, engine analyzers, and other test equipment.

Employers increasingly send experienced automotive technicians to factory training centers to learn to repair new models or to receive special training in the repair components such as electronic fuel injection or air conditioners. Motor vehicle dealers may also send promising beginners to factory-sponsored training programs. Factory representatives come to many shops to conduct short training sessions.

Job Outlook

Job opportunities for automotive technicians are expected to be plentiful for those who complete training programs in high school, vocational and technical schools, or community colleges. Persons without formal mechanic training are likely to face competition for entry-level jobs. Technician careers are attractive because they afford the opportunity for good pay and the satisfaction of skilled work with one's hands.

Employment of automotive technicians is expected to increase more slowly than the average for all occupations through the year 2000. Declining employment in gasoline service stations, together with little change in employment in automobile dealerships, will offset growth in independent automotive repair shops and other industries.

Nevertheless, the number of technicians is expected to increase because expansion of the driving age population will increase the number of motor vehicles on the road. The growing complexity of automotive technology increasingly necessitates that vehicles be serviced by professionals, contributing to growth in demand for technicians. In addition, if the average age of vehicles in operation continues to increase, a growing proportion of vehicle operating costs will be spent on repairs, and less on the cost of the vehicle.

Most persons who enter the occupation may expect steady work because changes in economic conditions have little effect on the automotive repair business. During a downturn, however, some employers may be more reluctant to hire inexperienced workers.

Exercise

1. On which characteristics does the ability to quickly diagnose mechanical problems depend?

2. Name five examples of areas in which automotive technicians may specialize.

3. Where is most of an automotive technician's work done?

4. What are some of the negative aspects of being an automotive technician?

5. How many people were employed as automotive technicians in 1988?

6. For whom did technicians primarily work?

7. What percentage of automotive technicians are self-employed?

8. How do most automotive technicians learn the trade?

9. Why is it increasingly more difficult to learn the automotive trade by working with experienced technicians?

10. Why is it becoming more important for a technician to understand electronics?

11. List some of the components in which electronics are being used other than engine controls and dashboard instruments.

12. Why are technicians becoming more involved in diagnosing electronic malfunctions?

13. What qualities do employers look for in person looking for trainee technician jobs?

14. What background do many employers regard as the best preparation for trainee positions?

15. Who usually furnishes hand tools for technicians?

16. Who usually furnishes power tools, engine analyzers, and other test equipment?

17. What kind of advanced training may an employer furnish for a technician?

18. For which automotive technicians are job opportunities expected to be plentiful?

19. How does the increase in employment of automotive technicians through the year 2000 compare to the average for all occupations?

A-3

Owning Your Own Business

Essential Elements: (a)(3)(A-D)

Unit Objectives:

After completing this instructional unit, you will be able to:

- *explain the organization and use of this manual*
- *explain the nature and outlook of the automotive technician's field*
- *explain the procedures for establishing your own business*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how to select a location for a business*
- *explain how to raise the capital necessary to start up a business*
- *explain three methods of organizing a business*
- *explain the various types of business records that must be maintained*
- *explain some of the tried methods of hiring and keeping good automotive technicians*

Building your own business is challenging and exciting. It will require you to develop many abilities other than repairing automobiles. You will be responsible for managing the financial aspects of the business, as well as providing leadership for your employees. Successfully operating your own business gives you a sense of pride. Providing jobs for those working for you and providing a service to the community is satisfying.

Along with challenges and satisfaction, you must consider the risks of operating your own business. Going into a business can be considered a *high risk* gamble. You can lose your entire life's savings. Even your reputation can suffer if your business fails.

Before you decide to open your own business, it is good to look at some of the factors involved in making a business a success. It involves much more than just being a successful automotive technician. In fact, the success or failure of the business probably will not involve your automotive skills as much as it will your business and personnel management skills. Let us look at some of the factors involved.

The Community

Of primary consideration when looking for a place to start a business is the economic condition of the prospective area. Some questions to which you will want answers are these: Is the population of the community declining or growing? How do most of the people make a living? Are the local industries expanding operations or slowing down? How many shops and stores have gone out of business in the last year or two? Obviously, a growing dynamic community will provide a greater probability of success than one on the decline.

You will want to learn something about the people themselves. Are they likely to need and use the services of a new automobile repair shop? Do most of them own cars? What is their average age? Do many of them commute long distances? What is the average annual income in the immediate area? People in a wealthy community tend to have their repairs done at the dealership where the vehicle was purchased. You want to target a population who can afford to have their vehicles repaired rather than doing it themselves.

Locating Your Shop

Where your business is located within the community is a very important factor. You must comply with zoning ordinances. A business cannot be built in an area zoned for residential dwellings. Traffic and parking must be considered. Is the shop easy to find by its address and by giving someone verbal directions? Are the streets in good condition and well laid out so the shop is easily accessible by automobile? Is there ample parking space for you and your employees and customers?

The kinds of businesses that neighbor your shop should be a factor when selecting a site. Do their services and products cater to the same type of customer that yours will? One would not locate an automobile repair shop in an area in which there were many vacant buildings. There is an old saying that empty buildings are bad neighbors. People tend to avoid doing business in areas with vacant buildings. Are there other automobile repair shops in your block? You do not want to share your customers with other shops.

People are creatures of habit. People who have used a shop for some time tend to want to stay with the shop when ownership changes. Sometimes it is better to purchase an established shop than to start a new one. If you are considering an existing shop, be sure to check on the volume of business done before you purchase it. The place might be losing money due to subtle economic changes in the community. There may be plans in progress to change the traffic flow, resulting in less traffic. You should check out the owner's reasons for selling. If there is any doubt, look somewhere else to start your own shop.

The Building

In most instances, it is better to rent a building for a new shop than it is to buy one. An ideal situation may be to lease a building with an option to buy.

Consider these areas when shopping for a building.

1. Does it have customer appeal? That is, does it look like an automotive repair shop? When competitive shops are equal, customers will use the one that has more appeal.
2. Does it have adequate:
   a. air conditioning for summer?
   b. heating for winter?
   c. electrical capacity with enough outlets?
   d. water and sewer to meet your needs?

   e. floor space for bays, equipment, parts room, and storage?
   f. natural gas or propane tank capacity?

3. If any of these are missing or inadequate, can the situation be corrected? If so, will the owner finance the job? You should not use start-up money for this.

4. Is the building large enough to allow for expansion as your business grows?

5. Has the building been inspected lately and been approved for safety factors? If not, the insurance premiums might be excessive.

6. Can the building be modified to meet the specifications of your shop? Can you afford the expense?

If the answers to the preceding questions are positive, you may decide that the property is what you need. If so, get an attorney's advice. There may be hidden clauses in the contract. The contract should provide for a term long enough to see if the business will succeed. It should allow for re-leasing at an agreed upon price. Consider this—your venture may fail. If you are legally bound by a contract that is too long, you may end up in bankruptcy.

Obtaining Required Capital

You need to know the *how* and *where* of getting the necessary capital to start your own shop.

You are the first and most important source of capital. This is known as *equity capital* or *venture money*, and without it you will be giving up the right to ownership.

Personal savings are the primary sources of venture money. Your savings are not limited to only the cash available in a savings account. It also includes everything you own. Life insurance policies, land, buildings, livestock, and valuable collections of all kinds may be counted. Of these, the cheapest money is probably that in a savings account. You will not have to pay interest on it. However, you will lose the interest it would have drawn if left in the savings account.

Life insurance policies that have been in effect a long while will have a cash value that can be borrowed from. Most will have a relatively low interest rate. An advantage of using this is that the amount borrowed can be kept and used as long as necessary. In case of your death, the benefits of the policy are reduced by the amount borrowed plus the interest owed.

The other valuables you have accumulated can be used to secure a loan from the several types of lending institutions. Even money in a savings account can be used in this way. These loans are usually for a short period of time.

One of the first steps you will take when starting a business is to establish a checking account with a commercial bank. Your *working capital* is kept there, allowing your business to pay bills by written checks. The canceled checks then become proof of payment and are absolutely necessary for income tax purposes. A canceled check is one that has been processed and paid through a bank.

Another valuable service a commercial bank can provide is lending money. There are often times a shop owner will need extra money. You may need the money for a bargain price on a modern piece of equipment. If your reputation in good, you should have no trouble getting a short-term loan.

Short-term loans range from 30 days to 6 months. You may be able to get an *unsecured loan* (signature loan) based on your good reputation. However, if the amount of money is large or if you are not very well known, you may have to put up collateral for a *secured loan*. This means you put up something you own that is worth more than the amount of the loan. If you *default* (do not repay the loan), the property goes to the lender to pay the debt when it *comes due* (matures).

Another important source of credit in the early days of a business are your wholesalers and equipment manufacturers. This is a form of borrowing known as *trade credit*. It means you have an open account and do not have to pay for your supplies immediately. Usually, trade credit is extended for 20 to 30 days and is interest free. However, this is different if the amount owed is very large or the time period is longer. In this instance, it is not uncommon for the supplier to charge interest. Since trade credit is so important to small businesses, a good reputation with these people is critical.

Business Organization

A shop may be owned as a *sole proprietorship*, a *partnership*, or a *corporation*. Each has both advantages and disadvantages, and selecting the best one will depend on many factors.

Sole Proprietorship. A sole proprietorship might be right for you if you fall into all the following categories: (1) You must either have or be able to borrow a sufficient amount of money. (2) You must have experience as an automotive technician. (3) You also must be willing to risk total unlimited liability for your business.

Proprietorship is the most common type of business organization in the United States. It is probably best for the beginner and for very small businesses that employ only a few people. Some of the advantages of sole proprietorship are these:

1. It is easiest to go into since it is the simplest form of organization.
2. Lawyers' fees are less than for the other types of organization.
3. Fees for licenses are lower.
4. There is far less government red tape.
5. The owner is the boss and decision maker.
6. Business profits are not shared with others.

There are, however, some disadvantages to being the sole owner of a shop.

1. It is more difficult to raise capital than for the other types of business organizations.
2. The owner must be a very talented individual with skills in automotive repair, business management, customer relations, advertising, and so on.
3. The owner has unlimited liability for business debts, employee actions, customer safety, etc. Unlimited liability is obligation to law without restriction.
4. A prolonged illness could very easily ruin the business.

5. Sole proprietorships have high failure rates.

Partnership. A partnership is a business that is owned and most often operated by two or more people. Its many advantages often persuade a sole proprietor to take a partner into a business. With more partners in a business, there is a bigger pool of ideas, skills, knowledge, and energy. Sole proprietors cannot expect employees to care for a business like they do, but they can with their partners.

It is much easier to borrow money when there are partners. There is a reason for this. They are all collectively (as a group) and individually responsible for the debts of the business. As in the case of the sole proprietor, this liability is unlimited. This means lenders feel secure when there are more than enough tangible assets. *Tangible assets* are items that are capable of being appraised at an actual or approximate value. Lenders want these assets to cover the loan in case of failure to pay.

As with any business arrangement, partnerships also have disadvantages to be weighed against advantages. Finding just the right partner can be difficult. The person needs to be interested in the same business, as well as have qualities and abilities that you might lack. Also, the person must be someone with whom you can get along. Remember, you will be working together eight or more hours a day, five or six days a week. Authority is somewhat difficult to define and divide between partners. This can lead to disagreements.

If one partner acts irresponsibly or makes a bad decision, all the others share in the consequences due to the unlimited liability. If it involves heavy financial loss, all partners can lose personal property that has nothing to do with the business itself.

Partnerships are difficult to dissolve, and problems come up if one partner dies or becomes incompetent.

You should hire an attorney to draw up a *partnership agreement* even if you go into partnership with an old trusted friend or relative. This is a legal document that spells out the duties and responsibilities of each member. It also discusses methods and procedures for running the business.

Corporation. A corporation is a group of associates (owners or stockholders) that has the legal right to do business as one person would. A corporation can do many things as an entity. It can own property, buy and sell a product or service, and contract with individuals or other corporations. It can also sue for damages and in turn be sued. In other words, a corporation is treated as an individual person. It has the same rights and privileges.

Before these rights are extended, a corporation must be chartered by the state in which it is located. A *charter* is a written order from authorities giving a group of persons the right to organize.

Legal fees for incorporating are higher than for forming other business organizations. Generally speaking, it is not best for a small business to organize as a corporation.

Record Keeping

Any business must keep certain records of their business. Some records are kept for the benefit of the business owner and some for the benefit of different governmental agencies.

Accounting system. An accurate method of keeping up with the financial condition of y our business is critical to the success of the business. You need to know how much money your technicians bring in and how much it costs to keep them on the payroll. You must know how much you are spending for parts, equipment, rent, utilities, advertising, insurance, taxes, and all other expenses as well as the total amount your business brings in. Without this information, you can be in financial ruin before you know it, and it will be too late to do anything about it. The only way to keep this information is to establish an accounting system. Generally, you should have an accountant set up your system if you do not hire an accountant to take care of these records.

Taxes. A business owner must obtain an employee identification(IE) number from the Internal Revenue Service. This number is used on forms submitted with social security and federal income taxes that have been withheld from employees' salaries.

In states with sales taxes, you must also have a state business identification number. This number is used on forms to submit sales taxes, as well as state unemployment taxes, state income taxes, and other forms required by the state.

Your business must pay federal unemployment taxes if it has paid a certain amount in wages in any calendar quarter and had one or more employees on the payroll at least some part of one day in each of 20 or more calendar weeks. State unemployment taxes are usually based on the taxable wage base for a quarter. In some state, the worker is also assessed through payroll deductions.

Some counties, towns, and cities impose other taxes. Examples include taxes on gross receipts of businesses and unincorporated business taxes.

Insurance. Three classes of insurance concern your business. They are (1) coverages that are essential for most businesses, (2) coverages that are desirable for many businesses, and (3) coverages for employee benefits.

Four kinds of essential insurance for your shop are fire insurance, liability insurance, automobile insurance, and workers' compensation insurance. You will probably want to add such things as windstorm, hail, smoke, explosion, vandalism, and malicious mischief to your basic fire insurance, as the additional cost is usually small.

Be sure your legal liability limits are high enough. Many lawsuits today are going as high as $1 million . Most liability policies now cover personal injuries such as libel, slander, etc. Check to see if these are in your policy before signing anything. Under certain conditions, your business may be subject to damage claims even from trespassers. Be sure that possibility is covered. Since fire legal liability insurance is not usually in the fire insurance policy, be sure it is in the liability insurance coverage.

Workers' compensation is backed by a law that requires an employer to (1) provide the employee a safe place to work, (2) hire competent co-workers, (3) provide safe tools, and (4) warn employees of an existing danger.

One desirable type of coverage for many businesses is business interruption insurance. This covers fixed expenses that would continue if fire or other peril closed the business temporarily. Failure or interruption of the supply of power, light, heat, and gas, as well as other disruptions, would be covered.

Another desirable type of insurance is that which covers burglary or robbery. A special comprehensive crime policy is available fort small businesses. It also covers loss by theft, destruction, disappearance of money and securities, by thefts by employees.

Personnel

Hiring the best people to perform the duties of the company is another key to the success of a business. After hiring, the workers must be trained and paid. If the workers are not happy in their employment, they will move to other jobs.

Hiring employees. Salaries paid to employees are the single most expensive cost of operation for most small businesses. This points out the importance of making the right choices in selecting employees. Making a profit is the name of the game. People must be hired who will do a day's work for a day's pay. The first step in doing this is to decide exactly what the responsibilities of the employees will be.

Both the employer and the employee should have a definite understanding of what is expected of the employee. The best way of defining job responsibilities is to write a job description. A *job description* is a written list of all duties and responsibilities involved in the position to be filled. The necessary skills and knowledge, pay and benefits, and prospects for advancement are included. By doing this, you may avoid two of the pitfalls of choosing employees: (1) hiring overqualified people who will not stay long or (2) hiring someone who cannot do the work.

Training. Never assume that a new employee can step into a job and be productive from the start. Even those with automotive experience will need some training to become familiar with procedures, equipment, etc. New employees just starting as automotive technicians will require a great deal more training than experienced ones. Most often, this training takes place on the job.

On-the-job training usually is done informally. However, there are several things you need in order to do the best job of teaching.

1. Try to learn exactly how much the beginner knows about the trade, and start from there.
2. Begin every lesson by explaining to the trainee what you are going to teach. People need to know what they are expected to learn.
3. Demonstrate a procedure slowly, making sure the trainee understands each step and the reason for it. Discuss what you are doing and encourage questions.
4. Allow the trainee to perform the operation while you watch closely and correct mistakes as they occur. This procedure should be repeated until it is done correctly.
5. Review what you have said and done. Do this by inspecting and discussing the job in the step-by-

step way in which it was done. Praise a job well done. If mistakes were made, tell the trainee what was done wrong. Also, tell what is to be done differently.

Personnel Relations

Compensation. You must make the extra effort necessary to hire the best people you can find. You must spend money and time to train an employee to do a job. It simply makes good sense to do your best to keep the person happy. There are many ways to do this. They range from a friendly pat on the back to a good increase in wages or better fringe benefits.

The word *compensate* means to counterbalance. We use it to mean that a fair day's work should be counterbalanced with a fair day's wages. A good thing to remember here is that you get what you pay for. Cutting back on wages to hold down overhead invites disaster. The least it does is destroy morale, but it also invites cheating and theft by employees.

Most shops pay automotive technicians strictly on a commission basis. One of the disadvantages of this is deciding who will get which job. A balance must be kept in assigning jobs to technicians. If not, one technician may get more jobs or better-paying jobs than others. This creates dissention among the technicians. Also, it is important to keep the technicians busy. While the shop doesn't have to pay technicians for slow time, good technicians will quit if there isn't enough work to keep them busy. Without technicians, the shop will close.

An advantage of working on commission is the incentive it develops. Labor charges for specific jobs are based on the flat rate book. The book may say four hours are to be charged to do a job. If the technician does it in three hours, he or she still gets paid for four hours. The extra hour can be used for another job. The faster and steadier technicians work, the more they can earn.

Fringe benefits. It has been shown through experiments that paying workers more money does not necessarily make them more productive. What does seem to matter in this respect is whether employees feel that management really cares about their welfare. There are many employers who show appreciation to encourage productivity and loyalty through what is known as *fringe benefits*. Fringe benefits are benefits, services, or goods received in addition to the normal wages or salary. A person beginning a new business often cannot afford many fringe benefits. However, as a business grows and employees demonstrate their loyalty and dedication to the business, fringe benefits can be tailored to fit the conditions. Below are listed several benefits to consider.

1. Merit raise—increase in salary (larger percentage commission) that recognizes large volume of work, quality of work, etc.

2. Longevity pay—bonus each pay period for length of service.

3. Life insurance and hospitalization—pay all or part of employee health insurance premiums.

4. Paid vacations and holidays—paid vacations are more effective if they increase with longevity.

5. Discounts—offering goods or services at dealer cost will make

employees feel privileged and appreciated.

This is only a short list of fringe benefits because they are constantly expanding as competitive companies attempt to attract and hold on to skilled workers. Small business owners must be aware of these trends. They must be careful that they do not become *training schools* for bigger companies with better fringe benefits.

Exercise

1. What kind of community should you look for when trying to locate a new business?
2. Why should you not locate your shop in an area in which many vacant buildings exist?
3. Why should you not locate your shop close to other automotive repair shops?
4. Why is it sometimes an advantage to purchase an existing shop rather than start a new shop?
5. Why is it important to check the volume of an existing business before you purchase it?
6. Why is customer appeal important?
7. Why should you get an attorney's advice before signing a contract to rent a building?
8. What is equity capital?
9. Your savings consist of which items?
10. What is the advantage of borrowing from an insurance policy?
11. Why are canceled checks important?
12. What is the most common type of business organization in the United States?
13. List six advantages of *sole proprietorship*.
14. What are the advantages of a partnership?
15. What is the financial responsibility of each partner in a partnership with regard to the actions of a single partner?
16. What should be spelled out in a partnership agreement?
17. Why is it absolutely necessary to have a reliable accounting system in your business?
18. Why is the employee identification number important?
19. What is the significance of the state business identification number?
20. List four kinds of insurance essential for your shop.
21. Under which policy is legal fire insurance usually found?
22. What are the four requirements under the law behind workers' compensation?
23. List two types of desirable insurance.

24. Which item is the most expensive cost of operating a business?

25. What is the best way of defining job responsibilities?

26. What are two common pitfalls shop owners make when hiring personnel?

27. How should you begin every lesson in on-the-job training?

28. Explain the demonstration procedure.

29. On what basis are most automotive technicians paid?

30. What is an advantage of being paid on commission?

31. What are *fringe benefits?*

Unit B

Shop Safety and Tools

B-1 **Shop Safety**
B-2 **Hand Tools**
B-3 **Measuring Tools**
B-4 **Power Tools and Equipment**

B-1

Shop Safety

Essential Elements: (a)(4)

Unit Objectives:
After completing this instructional unit, you will be able to:
- *explain the safety practices required of an automotive technician*
- *explain the tools and equipment used in an automobile repair shop*

Specific Objectives:
After completing this assignment, you will be able to:
- *name the primary cause of accidents*
- *explain how horseplay should be dealt with*
- *explain why loose clothing should not be worn in the shop*
- *explain why precision tools should be stored in a clean and safe cabinet*

Accidents do not just happen; they are caused. One of the primary causes of accidents is a careless attitude toward safety practices. Ordinarily, people give little thought to safety as they go about their daily lives. It is only after an accident has occurred that most people realize the importance of safety practices. For the person who has lost a hand, an eye, or some other part of the body, it is too late.

Horseplay. One of the first things the student should consider seriously is that the shop is a place to work. Horseplay is a dangerous form of amusement and has no place in the shop. Many young people like to scuffle and work off excess energy by indulging in rough horseplay. This is dangerous at any time, but particularly so in a shop full of potentially dangerous equipment. Horseplay has led to serious—even fatal—accidents. It should never be permitted, even in its most innocent forms (fig. 1).

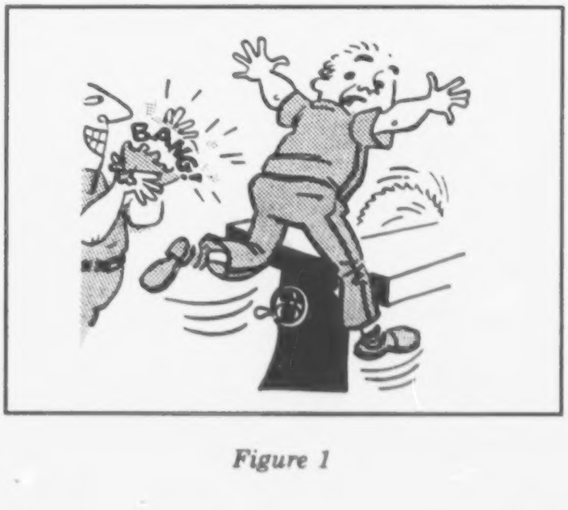

Figure 1

Lifting heavy objects. Lifting heavy objects, such as crankshafts or cylinder heads, is a common task in an automobile repair shop. The following suggestions are made to help prevent back injury.

1. Size up the load before lifting it, and get help if necessary.
2. Generally, do not lift a weight that is more than one-third of your body weight.
3. Lift the weight using your leg muscles, not your back.
4. Keep your feet close to the object that is being lifted, and, for better balance, keep one foot slightly closer to the object than the other.
5. Use a narrow stance, with your feet 8 to 12 inches apart.
6. Bend your knees, keeping hips lower than shoulders, and lift with your legs (fig. 2).

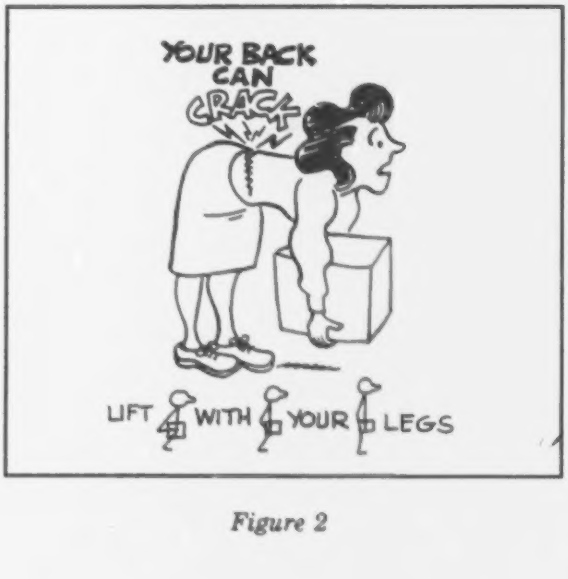

Figure 2

7. When two or more workers are lifting together, lift and lower at a given signal in order to equalize the load.

Lift the right way. Push the entire body upwards with the legs. This is easier and safer!

Cranes or lifts. Always place the crane or lift in position for a vertical lift, and be sure that the sling is placed for a balanced load and is in a position from which it will not slip. See that the ratchet lock or brake is in a position from which it will not slip. Stand clear of the load at all times. Before a load supported by a crane or lift is moved, it should always be lowered as close to the floor as possible, then blocked in such a way that it will not swing.

Air hoses. An air jet is often used for cleaning. Although it may appear safe enough, serious accidents have resulted from carelessness. Using an air jet to play a trick on a fellow worker is very dangerous. Always be careful that flying particles loosened by air blasts do not strike anyone. Never spin bearings with blasts of air to dry them. A thrown ball bearing can be as dangerous as a bullet fired from a gun.

Grinders. Examine the grinder to see that guards, tool rests, and shields are in place, and check the wheel to see that it is tight and that there are no cracks (fig. 3). Wear goggles or an eye shield. Small pieces should be held with pliers.

Batteries. Use a wrench, not pliers, to loosen nuts on terminal bolts. Remove terminals from the battery with terminal pullers. Lifting straps should be used to carry batteries. Gases from battery acid, formed during charging, are explosive, so open flames or sparks should be kept away from the battery at all times. When charging a battery or jump-starting a vehicle, always connect the black cable to the negative terminal and the white cable to the positive cable. A cross-connection could result in an explosion. Never carry a battery next to your clothes. If acid is spilled on the skin, wash thoroughly with water, and neutralize with bicarbonate of soda.

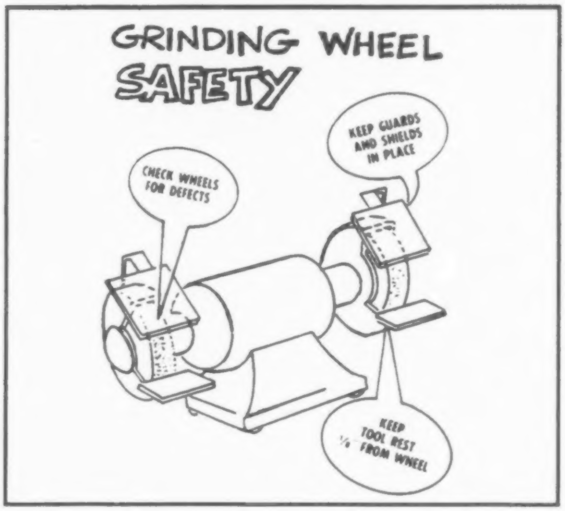
GRINDING WHEEL
SAFETY
CHECK WHEELS FOR DEFECTS
KEEP GUARDS AND SHIELDS IN PLACE
KEEP TOOL REST 1/8" FROM WHEEL

Figure 3

Up to 60,000 volts are developed in the ignition system. Since the amperage is so low, it presents no danger to most people. However, persons with heart trouble should be extremely careful when testing the ignition system.

Placement of equipment. Placement of equipment can affect the safety of a work situation. A disorderly shop can be the cause of falls. Materials and equipment, particularly creepers, should be placed so that the floor and aisles between automobiles are clear of hazards. The floor should be kept clean and free of oil and grease (fig. 4).

Moving parts. Moving parts are another potential source of harm. When it is necessary to work on one of the subassemblies with the engine operating, do as much of the work as possible with the engine stopped. For example, if test equipment must be attached, connect and disconnect the equipment with the engine still. Servicing parts near the radiator, fan, fan belts, or other moving parts is an unsafe practice and should be avoided when possible.

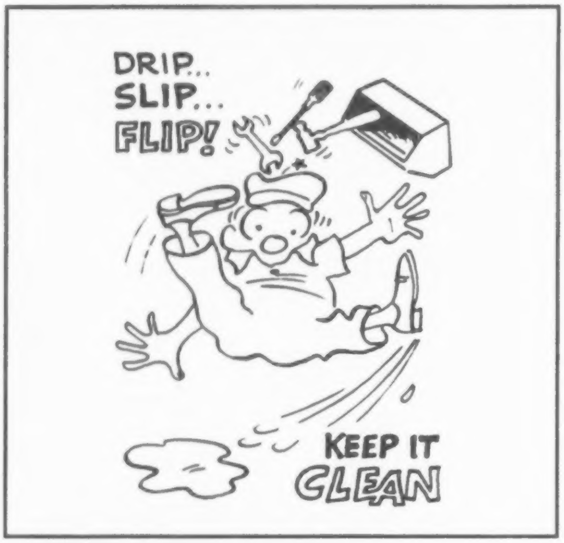
DRIP...
SLIP...
FLIP!
KEEP IT
CLEAN

Figure 4

Clothing. The loose ends of clothing or clothes will catch on rotating parts of machinery easily, so clothes worn in the shop should be fastened closely to the body (fig. 5). Never use a wiping cloth close to the revolving machinery parts. Rings and wristwatches are also potentially dangerous when worn close to machinery.

Measuring tools. No measurement at all is better than an incorrect one. For this reason, measuring tools such as micrometers, calipers, rulers, etc., must be kept clean and in a safe cabinet. Do not put them in a miscellaneous toolbox with tools that will damage them. Avoid carrying calipers and dividers in pockets or in such a way that the points might puncture the skin.

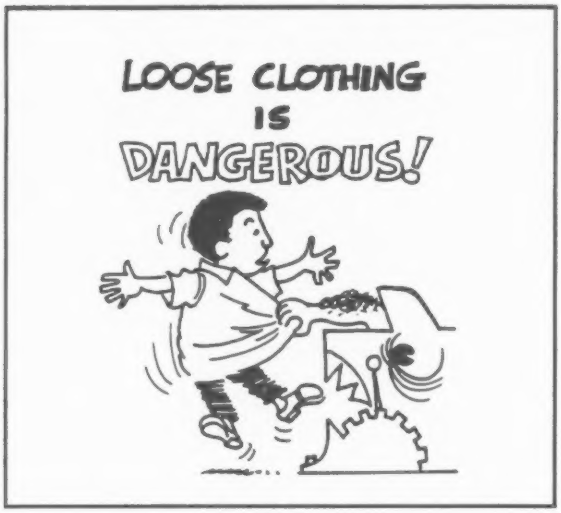
LOOSE CLOTHING
IS
DANGEROUS!

Figure 5

Power and other tools. Electrically powered hand tools should be equipped with a three-wire connector to prevent shock if they are not double-insulated (fig. 6).

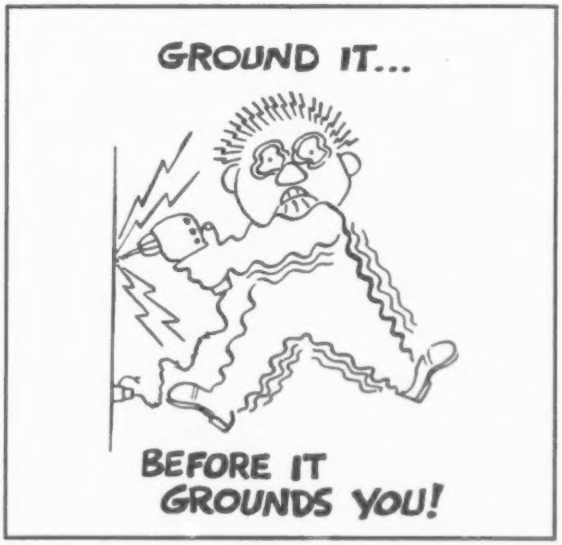
GROUND IT...
BEFORE IT
GROUNDS YOU!

Figure 6

Extension cords should be inspected for defects, and defective cords should be replaced (fig. 7).

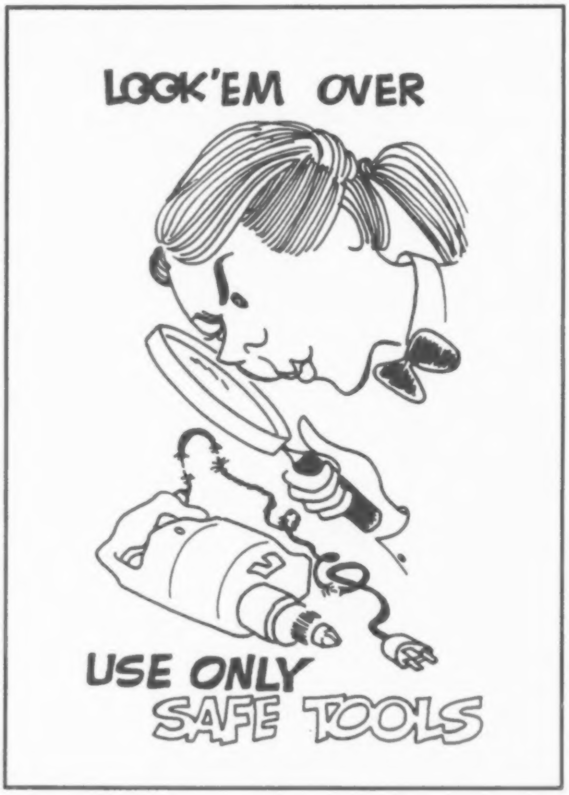
LOOK'EM OVER
USE ONLY
SAFE TOOLS

Figure 7

Be sure the cord is not in such a position that it will trip someone or be run over by jacks, creepers, and so on. Do not use unsafe tools. Check for burred heads on punches, chisels, hammers, etc. Keep the tool handles free from grease.

Working under an automobile. When working under an automobile, be sure the wheels are properly scotched. If an automobile is not supported by its wheels, be sure that the axles are properly supported by stands.

Exercise

1. What is one of the primary causes of accidents?
2. How should horseplay be dealt with by the management of the shop?
3. Which muscles are used to lift heavy loads correctly?
4. In what position should the load be carried when moving a load with a crane or lift?
5. Name three safety features of grinders.
6. Why should open flames near a battery be avoided?
7. What should be done if acid is spilled on the skin?
8. What type of accident can result from disorderly and cluttered shops?
9. When should test equipment be connected and disconnected to subassemblies of an engine?
10. Why should loose clothing not be worn in the shop?
11. Why should micrometers, calipers, and other precision instruments not be stored with other tools?
12. If they are not double-insulated, with what should electrically powered tools be equipped?
13. Why should calipers and dividers not be carried in pockets?
14. How should an automobile that has had its wheels removed be supported?

B-2

Hand Tools

Essential Elements: (a)(7)(D)

Unit Objectives:
After completing this instructional unit, you will be able to:
- *explain the safety practices required of an automotive technician*
- *explain the tools and equipment used in an automobile repair shop*

Specific Objectives:
After completing this assignment, you will be able to:
- *describe the hand tools discussed in this assignment*
- *explain the purposes and uses of the hand tools discussed*

Hand tools should be clean and in a workable condition. Greasy or broken hand tools can easily slip out of your hand, causing skinned knuckles or broken fingers. Before using a hand tool, check it for cracks, chips, burrs, broken teeth, or other dangerous conditions.

As an automotive technician, you should know how to care for each tool as well as the safety considerations for each one. You should also know the proper manner of designating types, sizes, and makes of tools. Of equal importance, you should know how to use the tools of your trade correctly. Never use a tool for any job other than that for which it was designed.

1. Purchase only quality tools.
2. Keep the tools in good condition.
3. Use the right tool for the right job.

Screwdrivers

The screwdriver is designed to drive and remove screws. Although there are many different types and sizes of screwdrivers, most of them are like the one in figure 1. The parts of the screwdriver are the handle, shank, and blade. Common screwdrivers for slotted screws are classified by size, according to the combined length of the shank and blade. This length varies from 2 1/2 to 12 inches. The diameter of the shank and the width and thickness of the blade are proportionate to the length of the shank.

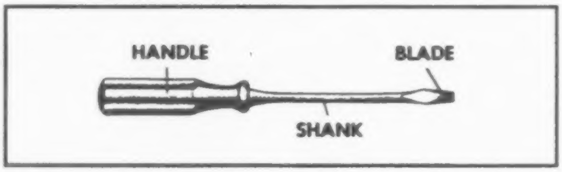

Fig. 1. Parts of a screwdriver for slotted screws. (Courtesy of General Motors Corporation)

In use, the blade should make a good fit with the slot in the screw (fig. 2). This prevents the screw slots from becoming burred and the blade tip from being damaged. At the same time, it reduces the force required to keep the screwdriver in the slot. Never use a pair of pliers to help turn a screw.

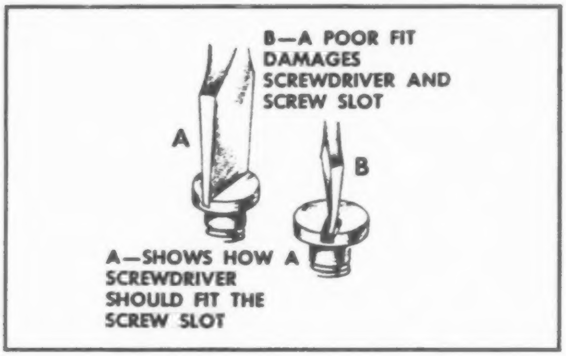
B—A POOR FIT DAMAGES SCREWDRIVER AND SCREW SLOT
A
B
A—SHOWS HOW A SCREWDRIVER SHOULD FIT THE SCREW SLOT

Fig. 2. A good fit is important. (Courtesy of General Motors Corporation)

Phillips-type screwdrivers do not have blades (fig. 3). They have only the shank and an X-shaped, fluted tip. The tip fits into Phillips-head screws that have two slots that cross at the center. The X-shaped tip holds the screwdriver in the center of the head better than the screwdriver for slotted heads. However, more downward pressure must be exerted to keep it in the cross slots than is required to keep the blade in the slot for the slotted screwhead. The sizes most often used by technicians are the 1-, 4-, 6-, and 8-inch Phillips screwdrivers.

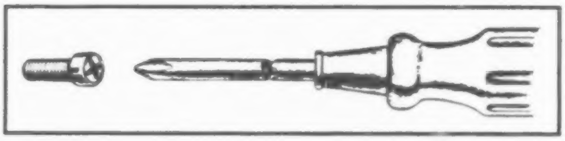

Fig. 3. Phillips-head screw and screwdriver. (Courtesy of General Motors Corporation)

Offset screwdrivers are used where there is not enough clearance to use a standard screwdriver (fig. 4). This type of screwdriver has one blade forged in line with the shank (in this case, also the handle) and the other blade at right angles to the shank. Both blades are curved outward near the tips, creating the offset handle. Where the swing space for a screw is limited, a technician using an offset screwdriver can change ends after each partial swing, thus working the screw in or out.

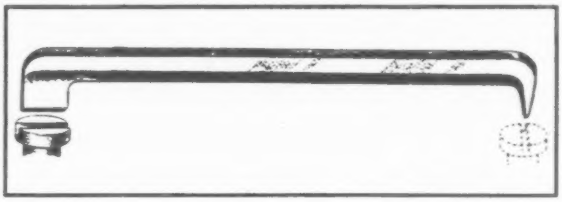

Fig. 4. Offset screwdriver. (Courtesy of General Motors Corporation)

Figure 5 shows the ratchet offset screwdriver, which is used mostly for light work and eliminates the need for changing ends. The type shown has a Phillips tip, but interchangeable standard tips may be obtained and placed in the ratchet handle.

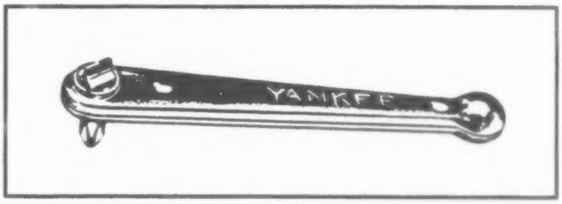

Fig. 5. Ratchet offset screwdriver. (Courtesy of General Motors Corporation)

Hammers

Ball-peen hammers (fig. 6) have a head especially designed for driving and forming metals. The peen is rounded, or ball-shaped, for flattening the ends of rivets, while the face is very slightly rounded and is used for driving chisels, center punches, and other metalworking tools. Ball-peen hammers come in sizes from 4 ounces to 2 1/2 pounds.

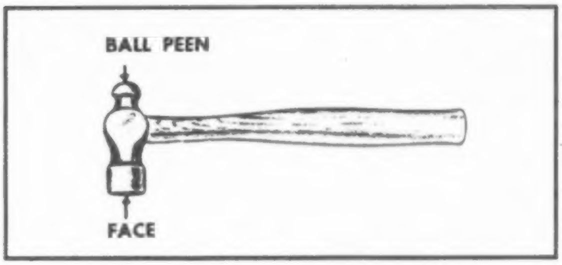

Fig. 6. Ball-peen hammer. (Courtesy of General Motors Corporation)

Soft hammers and mallets (fig. 7) are used to pound or drive objects or perform other operations where a steel hammer would mar or perhaps break the work. Soft hammers and mallets are made of plastic, copper, lead, rawhide, wood, and rubber.

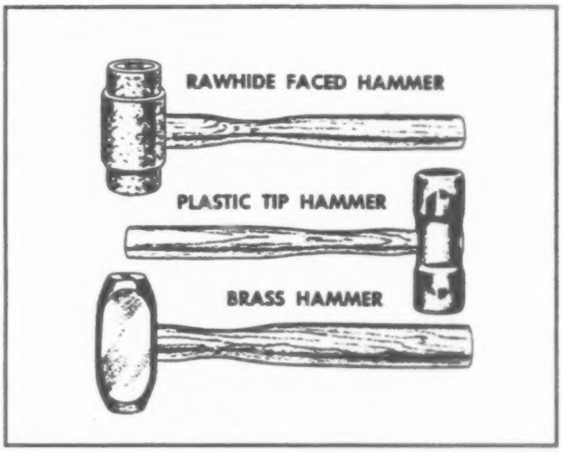

Fig. 7. Soft hammers and mallets. (Courtesy of General Motors Corporation)

Although the hammer is a simple tool, there is a right way to use it and a wrong way. Beginners usually choke or grip the handle too close to the head, reducing the force of the blow and making it harder to hold the hammer head in an upright position. The hammer should always be held near the end of the handle, regardless of the striking force required. The hammer should be held at such an angle that, when it strikes the object, the face of the hammer and the surface of the piece being hit will be parallel. This distributes the force of the blow over the entire hammer face and avoids damaging its edge (fig. 8).

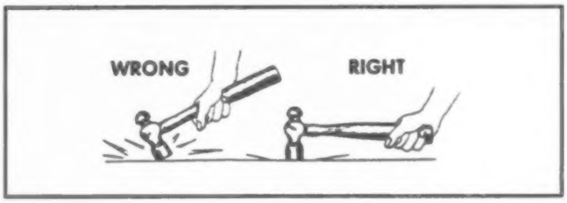

Fig. 8. Hold the hammer correctly. (Courtesy of General Motors Corporation)

Pliers

The size of pliers depends on overall length. Pliers are classified by the shape of their noses and by the functions they perform. For example, *needle nose, square nose,* and *flat nose* describe nose shapes, while *water pump, ignition,* and *electrician's* indicate the use of a particular type of pliers.

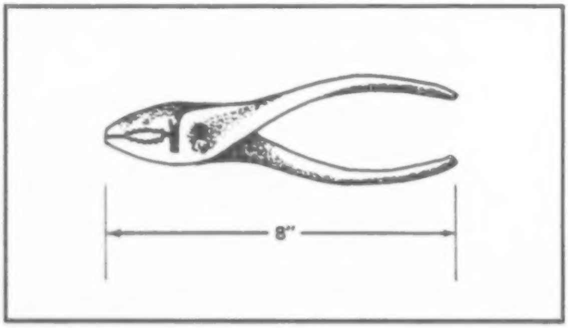

Fig. 9. Slip-joint pliers. (Courtesy of General Motors Corporation)

Combination slip-joint pliers (fig. 9) are by far the most common type. The slip joint permits the jaws to be opened to a wider position for gripping larger diameters. Combination pliers are available in sizes of 5, 6, 8, and 10 inches. Most combination pliers have shearing jaws for cutting wire and cotter pins.

Diagonal pliers (fig. 10) are so-called because the head is constructed with the cutting jaws at an angle of approximately 15° to the handle. They are used to cut and strip insulation wire, cut cotter pins to the proper length, spread cotter pins, and cut off wire close to terminals. Diagonals should never be used for holding objects and should not be used for cutting wire and pins too large for their capacity

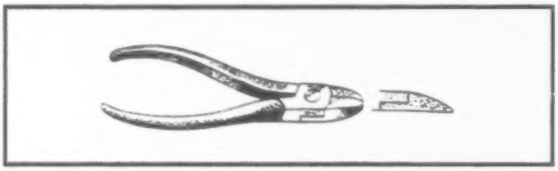

Fig. 10. Diagonal pliers. (Courtesy of General Motors Corporation)

Long-nose pliers (fig. 11) have long, slender jaws and are used chiefly in ignition and carburetor repair work. They may be used to hold small objects, especially in close places. Long-nose pliers with a *bent nose* are useful in places that cannot be reached with other pliers.

Needle-nose pliers are similar to long-nose pliers except that the nose actually comes to a point instead of the slightly squared point found on long-nose pliers.

Water-pump pliers have thin jaws that permit their use in confined places. They have a slip joint that permits the jaws to be adjusted to three positions for use on a variety of sizes of pipe fittings and bushings. Their long handles make their use in hard-to-get-at places easier and also provide extra leverage for tightening or breaking loose tight fittings.

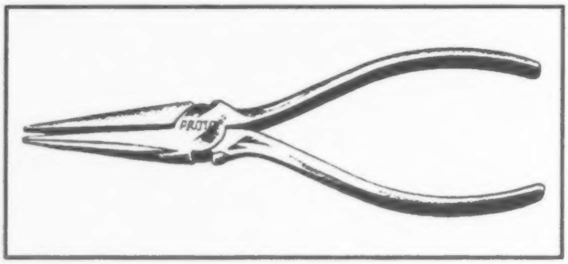

Fig 11. Long-nose pliers. (Courtesy of Proto Tools)

Channel-lock pliers (fig. 12) are a variation of water-pump pliers and are so-called because both jaws have channels or grooves, concentric with the joint pin, which engage each other in several positions. This permits work on various sizes of objects and prevents the jaws from slipping on the pin.

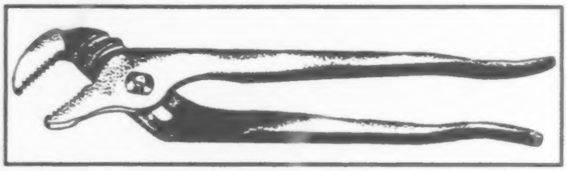

Fig. 12. Channel or groove slip-lock pliers. (Courtesy of Proto Tools)

Battery pliers should be used only for loosening and tightening the nuts on battery terminal lugs. Their jaws are shaped to fit the standard size 1/2-inch nut and made blunt to allow turning in close quarter. Some makes have one handle longer and flatter than the other and are used to pry frozen lugs off the battery terminal. Because of the corrosive action of the acid usually found on battery terminals, the pliers should be covered frequently with a film of grease and cleaned.

Ignition pliers are small slip-joint pliers with thin, serrated jaws, adjustable to three positions. Because of their small size, they are quite useful for work in close places, such as with generators, carburetors, distributors, and dash connections. Ignition pliers and battery pliers are the only kinds designed primarily for turning nuts that are difficult to turn with wrenches.

Locking pliers (fig. 13) have powerful, adjustable jaws that may be locked tightly on the work. Essentially a small vise, these pliers are useful in holding small work.

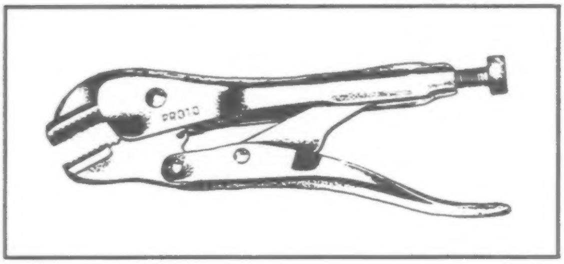

Fig. 13. Locking pliers. (Courtesy of Proto Tools)

Wrenches

Wrenches are by far the most-used tools in mechanical trades. So varied are the uses to which they are put, they must of necessity be designed in a wide assortment of types, sizes, and shapes.

The *open-end wrench* (fig. 14) is so named because it has an opening consisting of two parallel jaws that fit over the nut or bolt head. Ordinarily, there is an opening at each end. The jaws are set at an angle of 150° to the handle. This angle allows the wrench to be used in a restricted area of only 30°. By turning the wrench over, another 30° swing may be made by the wrench.

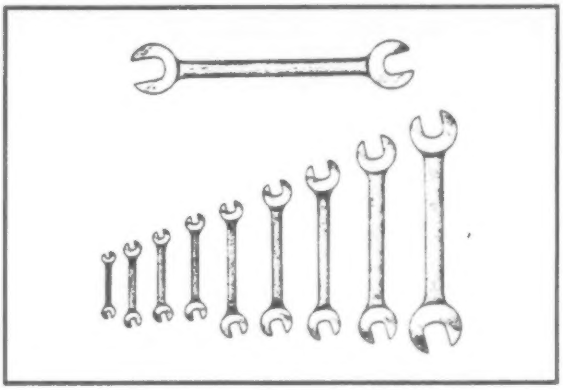

Fig. 14. Open-end wrenches. (Courtesy of General Motors Corporation)

The wrenches on each end of the handle are one size apart. To designate the size of an open-end wrench, you name both opening sizes, for example, a 1/2 by 9/16 wrench. The opening between the jaws is machined slightly oversize (usually 0.01 inch) to help engagement with the nut. Although the lengths of open-end wrenches have not been standardized, most manufacturers make the length about twelve times the opening size. They do this for two reasons: (1) This proportion allows greater leverage, since the larger the nut, the harder it is to turn and the more leverage needed. (2) Also, it prevents technicians from stripping the threads or breaking a small size bolt or screw by applying too much force with a wrench of the wrong proportions.

Box-end wrenches (fig. 15) completely surround or box in the nut. They usually have twelve points or notches inside (which are 30° apart), permitting the wrench to be swung in an arc as small as 30°. They engage the nut more securely than an open-end wrench and are therefore useful in breaking a tight nut or tightening up a nut the last few turns. However, since they must be lifted from the nut and then replaced at a new angle for each swing, they make the process of running-in or screwing slower than when an open-end wrench is used.

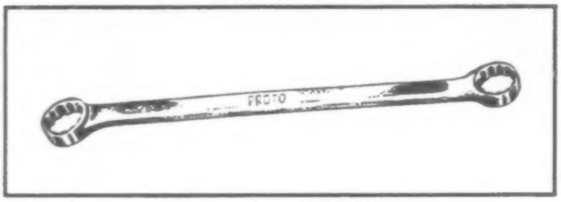

Fig. 15. Twelve-point box-end wrench. (Courtesy of Proto Tools)

Thus, some wrenches come with one open end and one box end. This combination wrench (fig. 16) allows the nut to be broken or tightened with the box end while the nut is run-in or off with the open end. Of course, the two ends of the wrench are the same size.

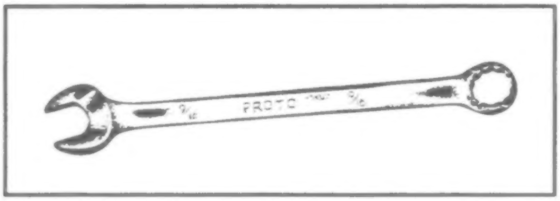

Fig. 16. Combination box and open-end wrench. (Courtesy of Proto Tools)

When a box-end wrench is used on a nut that is on a flat surface, the handle cannot be cocked enough to allow room for the fingers. Thus, box-end wrenches have handles that are not in line with the head to allow room. This angle is usually 15°. Special box-end wrenches come with handles in a variety of shapes or patterns. The S pattern and the half-moon pattern are commonly used for the purpose of clearing certain obstructions.

Socket wrenches (fig. 17) are the fastest and easiest type of wrench to use. They have all the best features of both open-end and box-end wrenches with the additional feature of being adaptable for use with a wide assortment of handles.

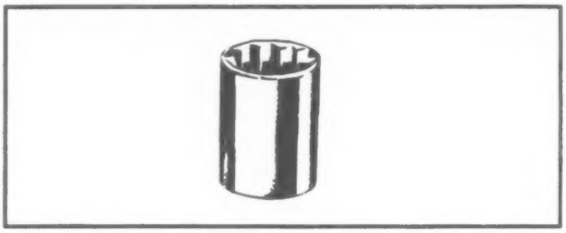

Fig. 17. Socket wrench. (Courtesy of Proto Tools)

The socket wrench has six or twelve points inside one end for engaging hexagon nuts, and four or eight points inside one end for square nuts (fig. 18). On the opposite end is usually a square hole that receives the drive of the handle. This square hole is usually either 1/4-, 3/8-, or 1/2-inch drive, depending on the size of the socket set. Heavy-duty impact sockets may have 1- or 1 1/2-inch drives.

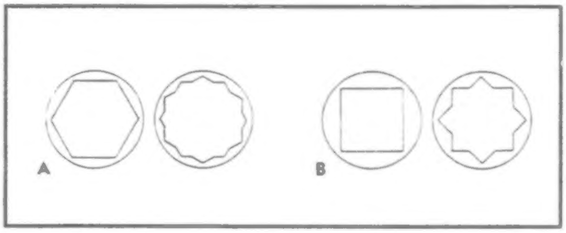

Fig. 18. (A) Six- and 12-point sockets for hexagon nuts; (B) 4- and 8-point sockets for square nuts. (Courtesy of Proto Tools)

The twelve-point socket is the most popular for hexagon nuts because it can be used to limit the swing to 30°. The six-point socket is usually used on small sockets and on impact sockets. Those used for impact wrenches undergo a special heat treatment to withstand impact use on heavy equipment. Both four- and eight-point sockets for square nuts may be used with impact wrenches. A spline drive is sometimes used on heavy-duty impact sockets used on square nuts.

The common types of handles (fig. 19) that may be used with each socket are the ratchet, sliding tee, speeder, hinge, socket driver, and torque.

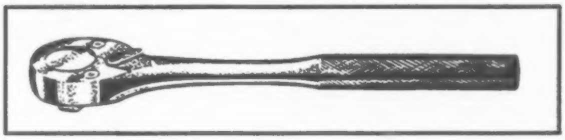

Fig. 19. Ratchet for socket wrench. (Courtesy of Proto Tools)

The *ratchet handle* makes it possible for a nut to be tightened or loosened without removing the handle, by means of a shifting lug. One of its primary advantages is that the ratchet handle may be used in close quarters where the angle of swing is even less than 30°. The amount of swing depends on the number of teeth or points on the ratchet.

The *torque handle* (fig. 20) is used to regulate the amount of force applied to the nut. This may be done by either of two methods. One method is to use a gauge on the handle that registers the amount of torque exerted. When the correct amount of torque is reached, the technician relieves pressure on the handle. The other method uses a torque-release mechanism in the handle to release the torque on the socket when a preset torque is reached. The amount of torque is expressed in foot-pounds.

Spanner wrenches (fig. 21) are special wrenches used with special round nuts. Round nuts have no hexagon or square head for engaging a wrench. Though used infrequently, they provide a strong nut in a limited space. They also prevent tampering, improve appearance, and are safer, with less possibility of injury to the hand. Spanner wrenches are provided with lugs or pins that engage notches or holes in the ends, or faces, of round nuts; or they may have hooks and pins that fit into holes or notches on the round part of the nut.

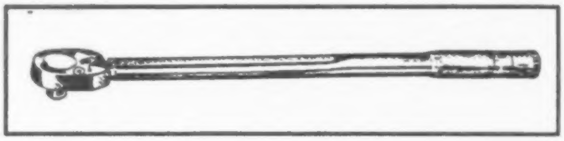

Fig. 20. Torque wrench. (Courtesy of Proto Tools)

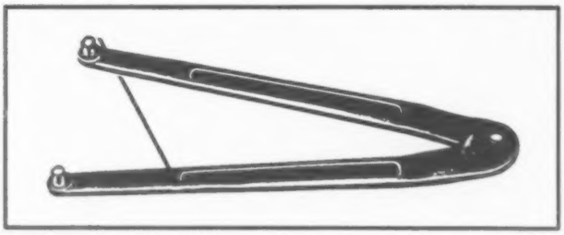

Fig. 21. Spanner wrench. (Courtesy of Proto Tools)

Crescent wrench is a trade name for a type of adjustable wrench that has become useful as a general utility wrench (fig. 22). It has some of the desirable features of open-end wrenches plus provisions for adjusting the opening between the jaws. Although it is useful in turning odd-sized nuts and bolts, a good technician prefers an open-end or box-end wrench if the proper size is available. The jaws do engage the nut rather securely, but must be readjusted often to maintain the proper fit.

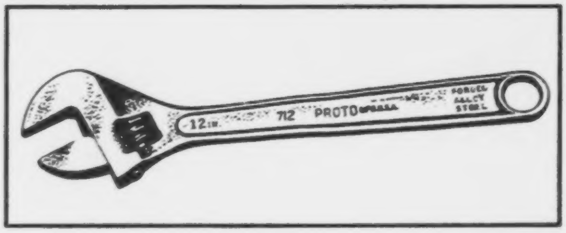

Fig. 22. Adjustable wrench. (Courtesy of Proto Tools)

Tough alloy steels have made it possible to make the Crescent wrench small enough and thin enough to be used in all but the closest quarters. Crescent wrenches are sized according to the overall length, which ranges from 2 to 24 inches. Their maximum jaw openings range from 1/8 inch to about 2 1/2 inches.

Exercise

1. What are three basic rules regarding the purchase, care, and use of hand tools?
2. How are common screwdrivers for slotted screws classified?
3. Why should the blade of a screwdriver fit the screw slot it is used on?
4. Describe the tip of a Phillips-type screwdriver.
5. Where are offset screwdrivers used?
6. For what kind of work are ball-peen hammers designed?
7. For what jobs are soft hammers and mallets used?
8. What will be the relative position of the hammer to the object it strikes at the instant contact is made if the hammer is held correctly?
9. What is the purpose of the slip joint in combination-joint pliers?
10. For what jobs are diagonal pliers used?
11. For what are long-nose pliers chiefly used?
12. What is an advantage of thin jaws on water-pump pliers?
13. What is the only purpose for which battery pliers are used?
14. In what respect are battery pliers and ignition pliers unique among pliers?
15. How did the open-end wrench get its name?
16. Why is the head of an open-end wrench cast at a 30° offset from the handle?
17. Most manufacturers make the lengths of wrenches about twelve times the opening size. What are the two reasons for this proportion?
18. Why are box-end wrenches better for breaking a nut loose or tightening a nut than an open-end wrench?
19. Why is the head of a box-end wrench set at a 15° angle?
20. What features make the socket wrench the easiest and fastest type of wrench to use?
21. How many points do socket wrenches for hexagon nuts have?

22. How many points do socket wrenches for square nuts have?

23. Why is the twelve-point socket most popular for hexagon nuts?

24. Name two advantages of using the ratchet handle with sockets.

25. For what purpose is a torque handle used?

26. What are the two methods of applying the correct torque to a nut using a torque wrench?

27. With which fasteners are spanner wrenches used?

28. For what job is the Crescent wrench particularly useful?

29. In what sizes are Crescent wrenches made?

B-3

Measuring Tools

Essential Elements: (a)(7)(D)

Unit Objectives:

After completing this instructional unit, you will be able to:

- *explain the safety practices required of an automotive technician*
- *explain the tools and equipment used in an automobile repair shop*

Specific Objectives:

After completing this assignment, you will be able to:

- *name the parts of a micrometer*
- *explain how to hold a micrometer when using it*
- *explain how to read a micrometer*
- *describe the measuring tools discussed*
- *explain how to use the tools discussed*

Micrometers

The micrometer, or simply mike, is a measuring tool that works on the principle of recording the advance of a fine-pitch screw through any number of turns or fractions of a turn.

Parts of the Micrometer

The various parts of a micrometer are shown in figure 1. Measurements are taken between the *anvil* and the face of the *spindle*. The spindle, which is threaded, is screwed inside the *barrel*, which is rigid with the frame. The spindle is turned by a connected *thimble*. As the thimble is turned, the spindle is screwed in and out of the barrel. The thimble has one end beveled. On this end twenty-five divisions for reading fractions of a turn are cut. The barrel has an index line 1 inch long on one of its sides, parallel to its axis. The index line is graduated (divided) in 1/40-inch divisions. Every fourth graduation is numbered from 0 to 10. Each graduation represents one complete turn of the thimble.

The *ratchet stop* may be used for turning the thimble. However, its primary purpose is to stop the advance of the spindle when the proper amount of tension is put on the object being measured. The *frame* is C-shaped to provide clearance for the work. It is rigidly constructed to prevent warping or springing during use. The *faces* of the spindle and anvil are perfectly parallel planes. They may be locked in a desired position by the knurled *clamp ring* or a *lever lock*.

Reading Micrometers

Reading to 1/1,000 inch. The 1-inch index line on the barrel is graduated in

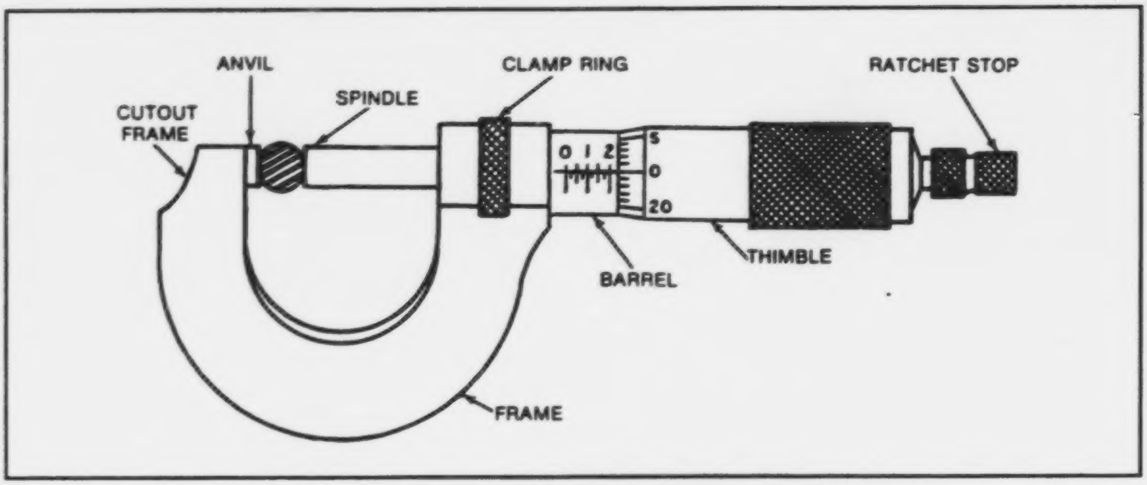

Fig. 1. Parts of a micrometer

1/40-inch divisions. The pitch of the micrometer screw is forty threads to the inch. This causes the spindle to advance 1/40 inch for each revolution of the thimble. As a result, one revolution of the thimble moves it one division on the barrel. In four revolutions, it moves four divisions, or 1/10 inch.

Each graduation is equal to 1/40 inch, or 0.025 inch. Moving one graduation moves the thimble 0.025 inch; two small lines represent a movement of 0.05 inch; three lines move the thimble 0.075 inch; and four lines move it 0.1 inch. By totaling the number of 0.025-inch graduations that are uncovered by the thimble, you may determine the reading between the numbered 1/10-inch divisions.

This does not account for the distance between the smallest graduations. This distance is measured in another way. Remember, one turn of the thimble advances it and the spindle 0.025 inch. Because the thimble is divided into twenty-five equal divisions around its circumference, each division represents 0.001 inch on the barrel. Therefore, determine which of the twenty-five divisions is in line with the index line. Add this amount to the reading that was explained in the preceding paragraph. This gives an accurate reading to 1/1,000 inch.

If the reading falls between the 1/1,000-inch graduations on the thimble, you may estimate the distance as 1/4, 1/2, or 3/4 and add the corresponding amounts—0.00025, 0.0005, 0.00075, respectively—to the reading.

Reading to 1/10,000 inch. For more accurate measurements, some micrometers have an additional vernier scale. It enables you to read to 1/10,000 inch. The vernier is divided into ten divisions that occupy the same space as nine of the 1/1,000-inch graduations on the thimble. Therefore, 1/1,000 inch divided by 10 equals 1/10,000 inch, which is the new measurement.

You can also measure to 1/10,000 inch in the following manner: Determine which of the numbered divisions on the vernier is lined up with a graduation (*any* graduation) on the thimble. Add this number expressed to 1/10,000 inch to the other readings.

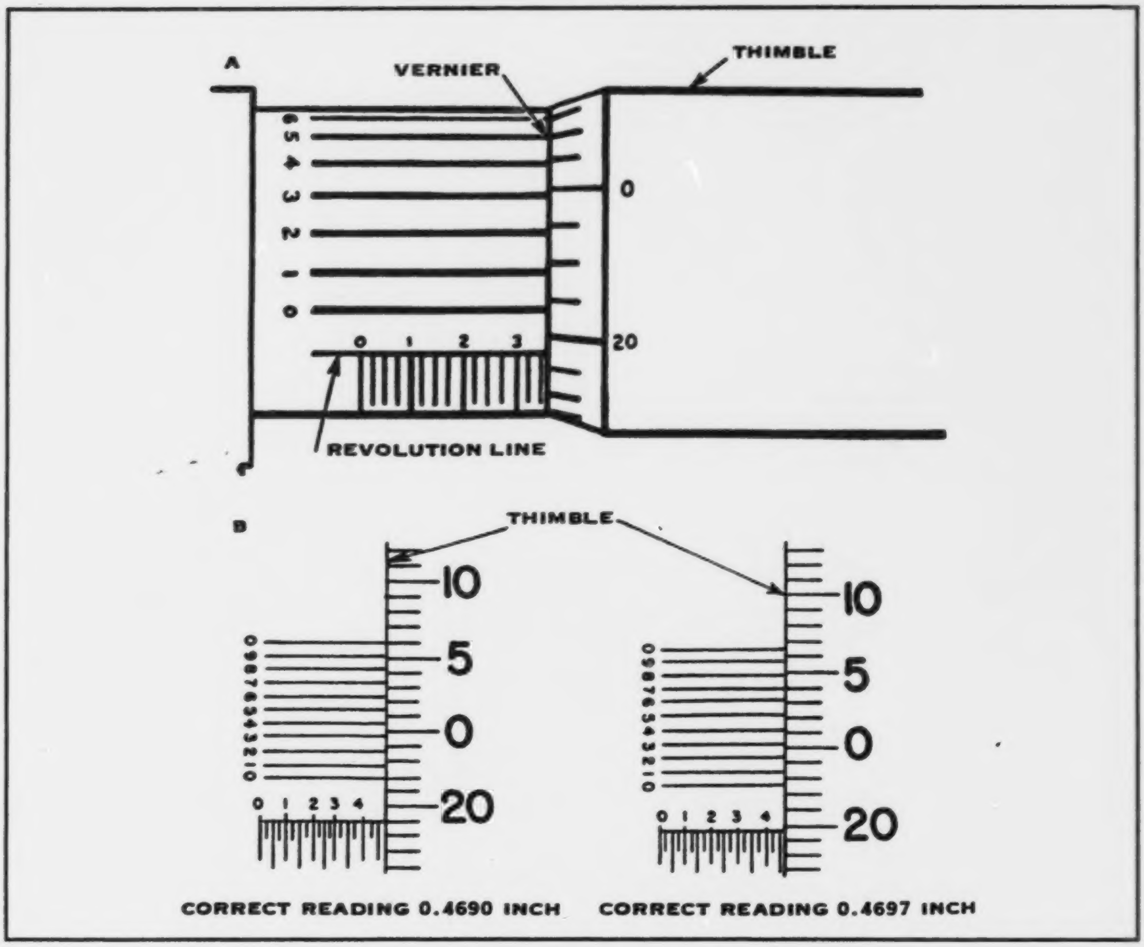
A
VERNIER
THIMBLE
6 5 4 3 2 1 0
0
20
0 1 2 3
REVOLUTION LINE
B
THIMBLE
10
5
0
20
0 9 8 7 6 5 4 3 2 1 0
0 1 2 3 4
CORRECT READING 0.4690 INCH
CORRECT READING 0.4697 INCH

Fig. 2. Reading a micrometer using the vernier scale

To illustrate, look at figure 2. Part B is a spread-out of the vernier scale on the micrometer shown in part A. The reading of 0.4697 is reached in the following manner: To the largest sum uncovered on the index line (0.45), add the number on the beveled scale even or just below the index line (0.019). Add to that sum the number on the vernier scale that lines up with any number on the beveled scale (0.0007). This gives you 0.45 plus 0.019 plus 0.0007, which equals 0.4697.

Sizes of Micrometers

Because the graduations on the barrel of the micrometer occupy only 1 inch, the tool can be used to measure only within the limits of 1 inch. The micrometer pictured in figure 1 is of this size and is called a 0-to-1-inch micrometer.

Larger micrometers are available in sizes of 1 to 2 inches, 2 to 3 inches, and so forth, up to 23 to 24 inches.

One type of micrometer has interchangeable anvils of 1, 2, and 3 inches in length. This makes one tool serve the purpose of four. It has a range from 0 to 4 inches.

Use of Micrometers

Miking small work. Small micrometers, such as the one that is 0 to 1 inch, are held in the palm of the right hand. The knurled portion of the thimble is held between the thumb and forefinger. The frame is turned downward. It is held with either the little finger or the ring finger of the right hand or both fingers pressing it against the heel of the hand (fig. 3).

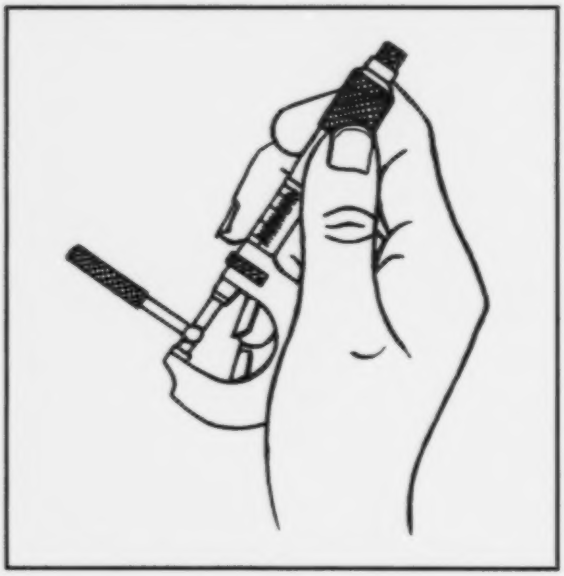

Fig. 3. How to hold a micrometer

The work is held between the anvil and the spindle face with the left hand. The thimble is turned with the thumb and forefinger of the right hand. This advances the spindle until it touches the work with a slight pressure. A correctly adjusted micrometer should be snug but free enough to slide over the work with a slight drag, which is felt in the fingers.

The micrometer should *never be clamped tightly* to the work. This not only causes an inaccurate reading but damages the tool as well. The proper amount of pressure is learned through considerable practice. You should not depend on the ratchet to make the proper adjustment, but should learn to feel what is the proper adjustment with your fingers.

In miking round stock, the axis of the part should be at a right angle to the frame of the micrometer. The spindle should be rocked slightly over the curved surface while the adjustment is being made. A slight drag is felt when the correct spot is contacted. After the correct adjustment has been made, the ring clamp or lever lock may be tightened to prevent the spindle from being moved accidentally. The micrometer may be read on the work, but it's better to remove it before reading.

Miking large work. Large-size micrometers are required for miking objects that are too large or too heavy to be held in the hand. The left hand supports the anvil against the work. The right hand manipulates the thimble in the usual manner. After the adjustment is made, the micrometer should be taken in the right hand in the middle of the frame. The micrometer is then moved over the work for the correct drag. When checking for a certain dimension, never set the micrometer first and then push it over the work. Instead, it should be unscrewed slightly and placed on the work, and the adjustment should be made.

Most measurements made with the micrometer are outside measure ments. The term *micrometer* generally indicates that the tool is an outside micrometer. If a micrometer is of any other type, the name includes its usage—for example, inside micrometer or depth-gauge micrometer.

Inside Micrometers

For measuring inside diameters, such as the bore of cylinders and inside parallel surfaces, specially constructed inside micrometers are needed (fig. 4). The head (thimble, barrel, threads, etc.) is identical to that of the outside micrometer, but the tool has no "C" frame. Steel expansion bars or rods that are fastened into the head serve as one contact point, while the other is fastened on the end of the thimble.

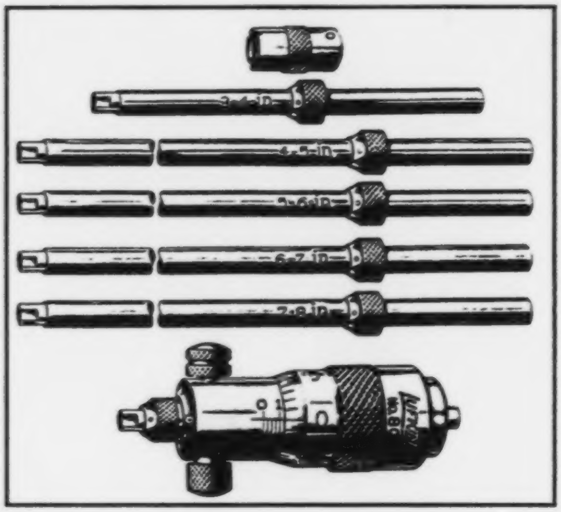

Fig. 4. Inside micrometer with extensions. (Courtesy of Lufkin Rule Co.)

Rods of different lengths give the tool a range of from 2 inches up to any desired amount. The shortest—1 to 2 inches—gives a range between these limits; the 2-to 3-inch type has a range between 2 and 3 inches; and so forth up to 2 feet or more.

The contact points are rounded to permit accurate contact with either parallel surfaces or inside curved surfaces. Some inside micrometers are provided with a handle that screws at right angles to the barrel and permits the tool to be inserted several inches into a cylinder.

Depth Gauges

Depth gauges (fig. 5) are used to measure the depth of drilled hole, recesses, and the like. They consist of a *movable blade or rod* at right angles to the head. The readings are taken from three types of scales: (1) the 64th-inch scale, (2) the vernier scale, and (3) the micrometer. The micrometer-type gauge has extension bars or rods that extend the range to any desired amount.

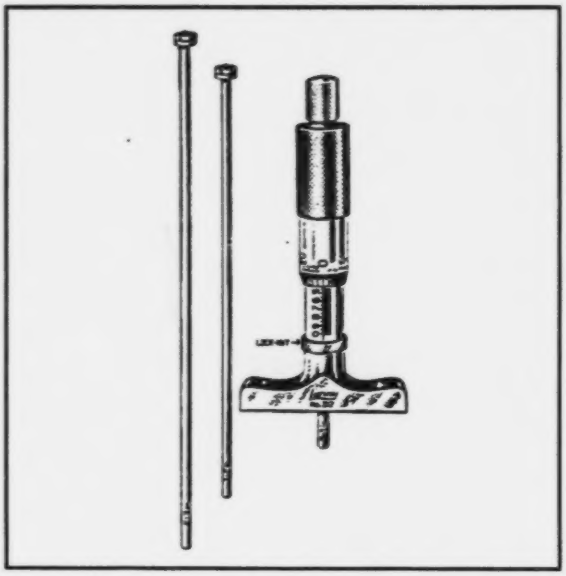

Fig. 5. Micrometer depth gauge. (Courtesy of Lufkin Rule Co)

Calipers

Calipers (fig. 6) are not actually measuring tools in the strictest sense but are designed for the purpose of transferring measurements from measuring tools to the work or from the work to measuring tools. Technicians usually use either (1) *outside calipers* for transferring outside measurements or (2) *inside calipers* for transferring inside measurements.

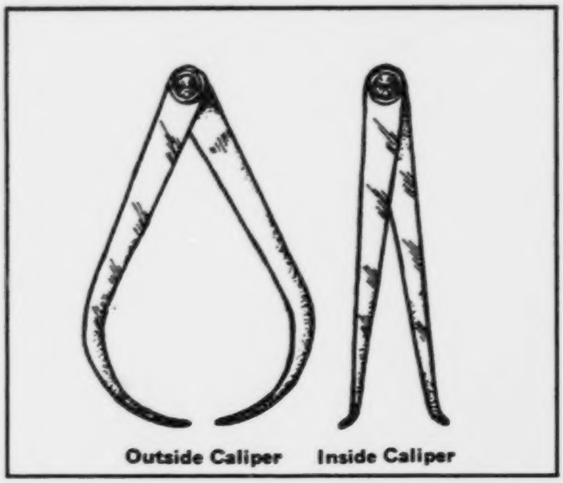

Fig. 6. Outside and inside calipers. (Courtesy of Lufkin Rule Co.)

Telescoping Gauges

The telescoping gauge (fig. 7) is another type of measurement-transferring tool that is used chiefly in measuring the bore of cylinders. The tool consists of a head and a handle set at right angles to it. The head has two cylinders of unequal diameter. The smaller, called the plunger, telescopes into the larger against spring tension when in the closed position.

The tool is inserted into a cylinder by means of the handle with the plunger locked in the closed position. When the head is at the right place, the locking screw in the end of the handle is unscrewed a fraction of a turn, allowing the plunger to expand. The ends of the telescope head will contact the walls of the cylinder under a slight pressure. The locking screw is then tightened, holding the plunger at the setting. The tool is removed, and the setting is read with an outside micrometer.

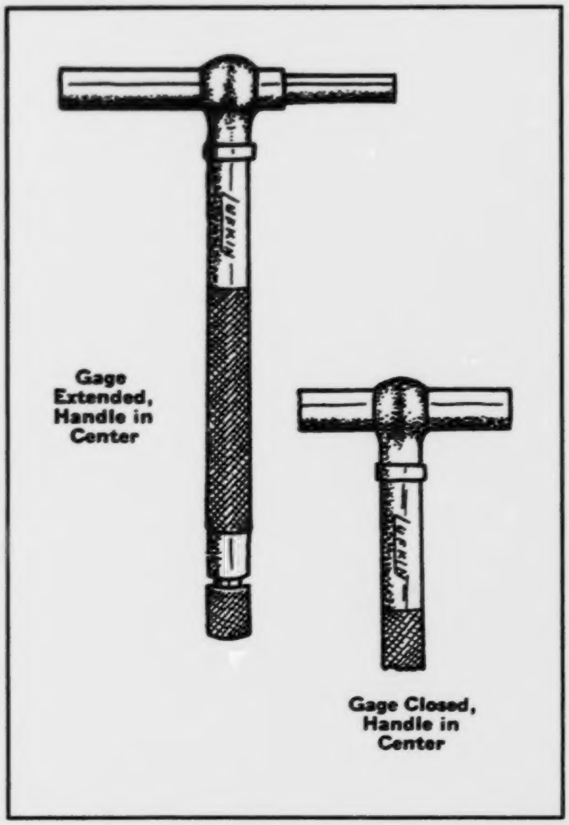
LUFKIN
Gage Extended, Handle in Center
LUFKIN
Gage Closed, Handle in Center

Fig. 7. Telescoping gauge. (Courtesy of Lufkin Rule Co.)

Automotive Feeler Gauge

Bent-wire feeler gauges (fig. 8A) are used to check the spark plug gap and the voltage regulator cutout gap in thousandths of an inch. They consist of several steel wires of different thicknesses, mounted in a case on a pivot screw. The ranges of wire thicknesses vary according to use. However, a typical gauge could have a range from 0.022 inch to 0.040 inch.

Bent-blade feeler gauges (fig. 8B) are similar to wire feeler gauges except that blades replace the wire gauges. Blade feeler gauges are used to set the gap between the points in the distributor and regulator and to set the spark plug gap. No single gauge set contains the entire range of thicknesses; rather, it has only those used most often for a particular type of work. By combining two or more blades, a wide range of thicknesses may be obtained.

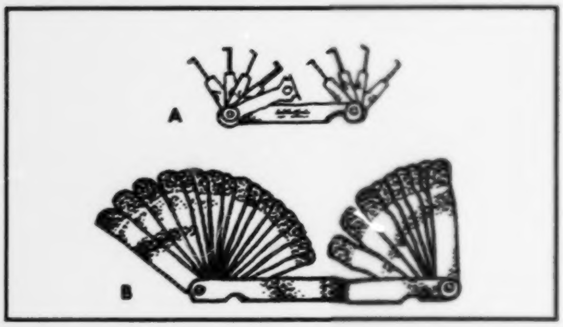

Fig. 8. (A) Bent-wire feeler gauge; (B) bent-blade feeler gauge

Both wire and blade feeler gauges are used by inserting different sizes of gauges between the surfaces being gauged until the one that best fits is found. The gauges should be free enough to be moved but tight enough for the fingers to feel a slight binding or drag—hence, the term *feeler gauge*. Both kinds have electrode benders to adjust spark plug gaps.

If a blade has become battered or bent, it is no longer useful, particularly in combination with another blade. The blades must be wiped clean of foreign matter before and after using.

Exercise

1. Name the parts between which measurements are taken on a micrometer.
2. Which part is used to adjust the micrometer to the thickness of the part being measured?
3. What is the purpose of the graduations on the thimble?
4. What is the purpose of the graduations on the index line?
5. What is the distance between the graduations on the index line?
6. What is the distance between the divisions on the thimble?
7. What is the smallest measurement permitted by the vernier scale?
8. How is the reading to 1/10,000 inch taken?
9. Within what distance do the limits of all micrometers fall?
10. What is the largest size of micrometer?
11. Explain how to hold a small micrometer properly.
12. What are the results of clamping the work too tightly?
13. What step should be taken to ensure that the full diameter of a round work is between the faces?
14. How are micrometers held when miking objects that are too large or too heavy to hold?
15. Why are the contact points of inside micrometers slightly rounded?

16. What are the three types of scales used on depth gauges?

17. For what purpose are calipers actually designed?

18. Of what does a telescoping gauge consist?

19. How is a telescoping gauge held in place after the measurement has been taken?

20. For what purpose are bent-wire feeler gauges used?

21. For what purpose are bent-blade feeler gauges used?

22. How is a wider range of thicknesses obtained than those available in the feeler gauge blades?

B-4

Power Tools and Equipment

Essential Elements: (a)(7)(D)

Unit Objectives:

After completing this instructional unit, you will be able to:

- *explain the safety practices required of an automotive technician*
- *explain the tools and equipment used in an automobile repair shop*

Specific Objectives:

After completing this assignment, you will be able to:

- *list the most commonly used power tools and equipment in automotive service*
- *describe the use of power tools and equipment*
- *compare the advantages of electric, pneumatic, and hydraulic tools*
- *list safety precautions to observe when using power tools*

Three main categories of power tools are used by automotive technicians. They are pneumatic (air), electric, and hydraulic. Most power tools used by technicians are either pneumatic or electric. The very power that makes these tools useful and laborsaving also makes their use dangerous. For this reason, you should know how to properly use power tools in a safe manner. One of the first precautions to be taken with any power tool is to read the operating instructions supplied by the manufacturer. If you are unfamiliar with a power tool, ask for a demonstration of the proper use of it before you attempt to use it.

Pneumatic Tools

Pneumatic tools are powered by compressed air. An air compressor, usually driven by an electric motor, pumps air into a large storage tank. Metal air lines carry the air from the tank to various locations in the shop. At different locations, air connections are made available for the technician to hook a flexible air hose to the metal lines. These air hoses are connected to the air-driven tool. The compressor is regulated by on-off pressure switches which maintain a preset pressure in the system.

The advantage of using air tools is that they are lighter and more compact than electric tools. They eliminate the dangers of electrically powered tools. They also require little maintenance. However, it is vital that they be lubricated before use. This protects the life span of the tool.

Some of the more common air tools are described in the following paragraphs.

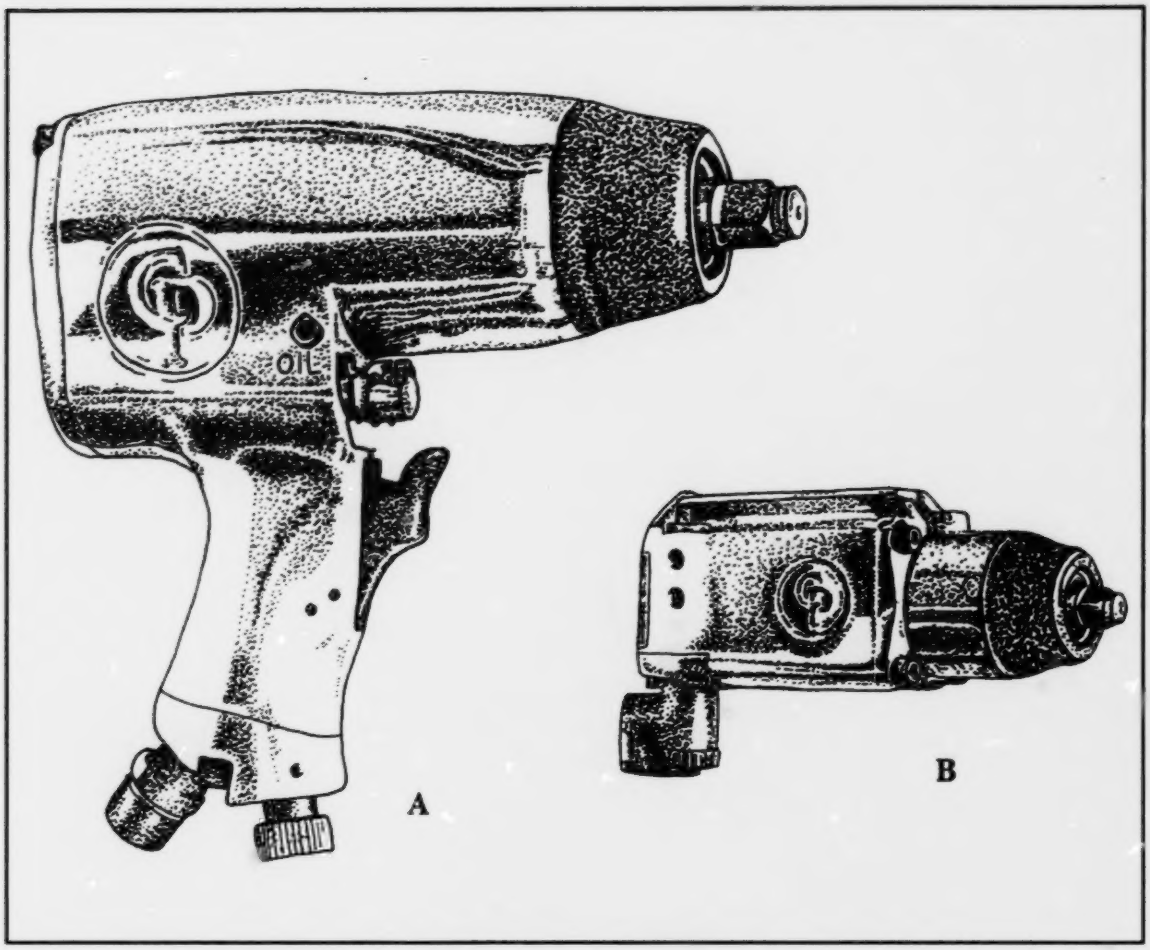

Fig. 1. (A) Pistol-grip drill; (B) Butterfly drill. (Courtesy of Chicago Pneumatic)

Air or impact wrenches provide a fast means of installing or removing bolts and nuts. Pistol-grip (fig. 1A) and butterfly (fig. 1B) are the two types of impact wrenches. As is common in all air tools, the torque is imparted by the driving head. The driving head, which is driven by compressed air, in turn drives the socket which is attached to the fastener head.

Impact wrenches come in 3/8-, 1/2-, and 3/4- inch drive sizes. An inexperienced technician should exercise care to prevent overtightening or leaving the nut or bolt loose. An impact wrench set normally comes with sockets that fit the drive. Impact sockets are built stronger than regular drive sockets. Therefore, they should never be interchanged. The impact socket can be distinguished from a regular socket since it is usually flat black, and a regular socket is usually chrome.

Air chisels or impact hammers (fig. 2) are used for cutting operations, such as cutting sheet metal on the body of the vehicle or cutting rivets and bolts. Several different types of cutters are available for the air chisel. Most air hammers have steel retainer springs to prevent the cutter from flying off the chisel. However, if the tool does not have such a safety device, it is important that the cutter be pressed against the work piece when using the air chisel. If not, the cutter will fly out of the hammer or chisel when the air is turned on.

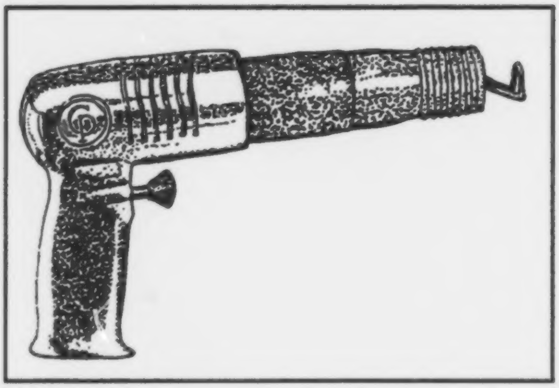

Fig. 2. Air impact hammer. (Courtesy of Chicago Pneumatic)

The **air gun** is used to help clean parts washed in solvents. It may also be used to blow dust and loose dirt off a part. Extreme caution must be exercised when using the air gun. Eye protection must be worn, and the air should never be directed at anyone. Parts containing asbestos, such as brake and clutch parts, should never be air-blown. Asbestos can cause cancer.

The **air drill** (fig. 3) is excellent for many types of repair jobs because of its speed adjustment capabilities and power output. With the proper attachments, air drills can drill holes, grind, polish, and clean parts. One example of its use is with the rotary brush. The rotary brush is used to clean old gasket materials, carbon deposits, and rust on the engine. Care must be taken when using the drill to protect against flying bits of broken drill bits, grinding stones, and steel bristles from the rotary brush.

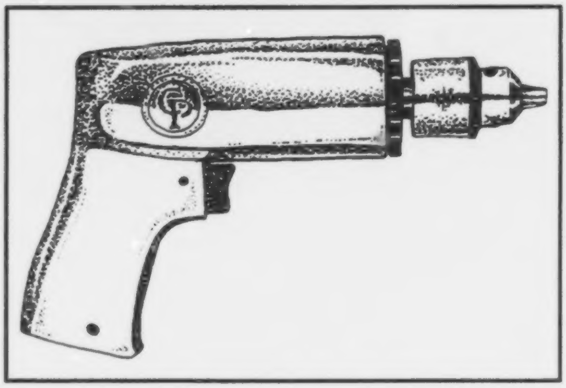

Fig. 3. Air drill. (Courtesy of Chicago Pneumatic)

Electric Tools

Electric-powered tools may be either portable or stationary. The most common electrical power tools are the drill press, portable drill, and grinder.

The **electric drill press** (fig. 4) is used to drill holes when the work can be brought to the drill press and for large or precise jobs. It is used to drill, ream, and countersink holes.

The **portable drill** (fig. 5) is used where small holes need to be drilled in work that cannot be carried to the drill press. Both types of drills use a twist drill. Twist drills may be carbon or high-speed steel. The high-speed steel bits are more useful because of their ability to be operated at a higher speed and their ability to resist heat. All work should be clamped to the drill table before it is used.

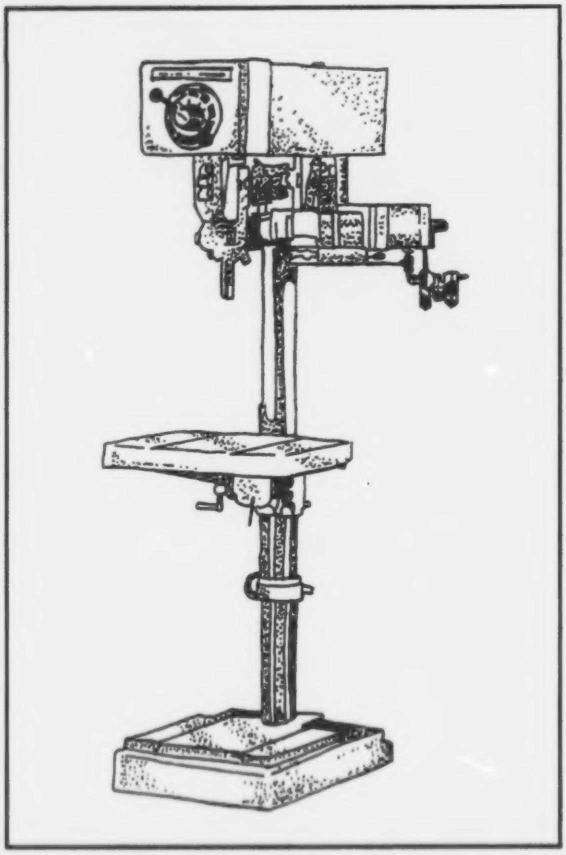

Fig. 4. Floor drill. (Courtesy of Chicago Pneumatic)

The **portable grinder** is often used to grind metal parts on vehicles or welded parts. The **pedestal grinder** is used to sharpen tools, touch up small parts, and burring parts. Wire brush wheels can be mounted on the grinder to buff parts and to clean them. Eye protection should be worn when using a grinder.

Hydraulic Tools

Hydraulic-powered tools are operated by the pressure of the hydraulic fluid pumped into the hydraulic cylinder that operates the ram. Hydraulic power tools include bumper lifts, floor jacks, transmission jacks, and portable cranes. A hydraulic press is another type of hydraulically powered tool.

Floor and end jacks are used to raise the vehicle a short distance, usually less than 6 inches. To avoid damage to the vehicle, the jack should be placed under a solid part of the car. Ordinarily, this will be the axle or frame. Once the vehicle is raised, jack stands should be place under the vehicle and the wheels blocked before work is done.

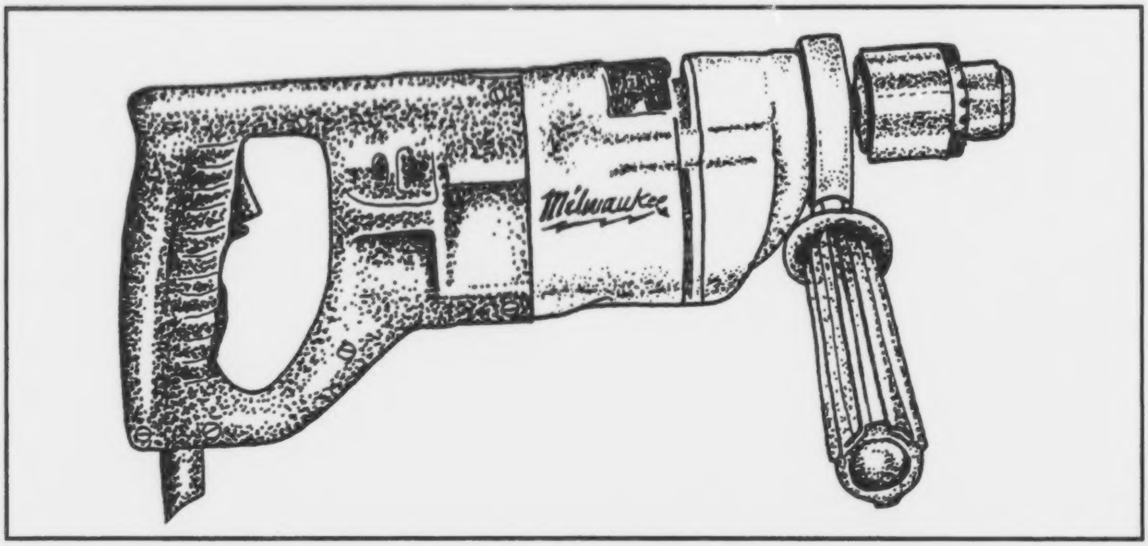

Fig. 5. Portable electric drill. (Courtesy of Chicago Pneumatic)

Exercise

1. Name the three categories of power tools used by automotive technicians.
2. Why is it important that you know how to properly use power tools?
3. What is one of the first precautions to be taken with any power tool?
4. What should you do before using a tool with which you are unfamiliar?
5. What are the advantages of using air tools rather than electric tools?
6. What type of maintenance is required of pneumatic tools?
7. What are the two types of air or impact wrenches?
8. Impact wrenches are made with what sized drives?
9. What should an inexperienced technician try to avoid while learning to use an impact wrench?
10. What distinguishes an impact socket from a regular socket?
11. What usually prevents the cutter on an air chisel from flying off when the air is turned on?
12. What should be done to prevent the cutter from flying off if the air chisel has no steel retainer spring?
13. What kind of personal protection equipment should be used when cleaning parts with an air gun?
14. Why should parts containing asbestos never be air-blown?
15. What characteristics makes the air drill an excellent tool for many types of repair jobs?
16. List four different types of jobs an air drill can perform.
17. What failures should you guard against when using an air drill?
18. What kind of drill jobs are performed on drill presses?
19. What kind of drill is used in electric drills?
20. What kind of material is used to make drills for electric drills?
21. What kind of jobs are performed on pedestal grinders?
22. What kind of jobs are performed on grinders with steel wire brushes?
23. Where should a floor jack be placed in order to prevent damage to a vehicle when lifting it?
24. What should support a vehicle once it has been raised by a floor jack?

Unit

C

Basic Electricity and Electronics

C-1 Fundamentals of Electricity
C-2 Circuit Analysis
C-3 Conductors and Resistors
C-4 Magnetism
C-5 Schematics (Electrical Road Maps)
C-6 AC and Computer Signals
C-7 Semiconductor Diodes
C-8 Transistors
C-9 Computer Circuits

C-1

Fundamentals of Electricity

Essential Elements: **(gg)(1-3)**

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain the difference between a conductor and an insulator*
- *use Ohm's law to calculate the voltage*
- *use Ohm's law to calculate the current*
- *use Ohm's law to calculate the resistance*
- *explain the difference between conventional current flow and electron flow*

Nature of Matter

To understand how electricity flows and where an electrical charge comes from, you need to examine the atom. In 1913, Niels Bohr proposed a model of *an atom with a nucleus in the center and the electrons flying in orbits around the nucleus.*

Orbits are labeled, starting with the first or inside orbit. The first orbit is labeled **K**, the next labeled **L**, and so on through the alphabet, with each orbit representing a certain energy level. *If an electron moves to an orbit that is farther away from the nucleus, it will gain more energy. When it falls back into its original orbit, the electron will give up that energy as light radiation.* Atoms can be excited by adding energy to them to cause the electrons to move between energy levels (orbits) and give off light.

Each orbit in an atom will have a certain number of electrons. The **K** orbit will have two electrons when it is full. It will always be full if there are electrons in the next outer orbit. The **L** orbit will have eight electrons, and the **M** orbit will have eighteen electrons when it is full. This rule changes for the outer orbit of an atom. *A full outer orbit has only eight electrons.* If the **M** orbit were the outer orbit, it would be full with eight electrons. The **N** orbit would be full with eight electrons if it is the outer orbit.

An atom with a neutral charge will have an equal number of electrons and protons. The protons have a positive charge and are located in the nucleus.

You learned in chemistry that there are approximately 100 elements. Each element is made of one type of atom. Except for some inert gases, the atoms in an element will be joined in some particular pattern.

The copper atom, shown in figure 1, will share its outer orbit electron with its neighbors, combining with other copper atoms to form copper metal. Copper has 29 electrons in orbits around the nucleus. Notice that *the outer orbit has only one electron.* Remember that a full outer orbit will have 8 electrons.

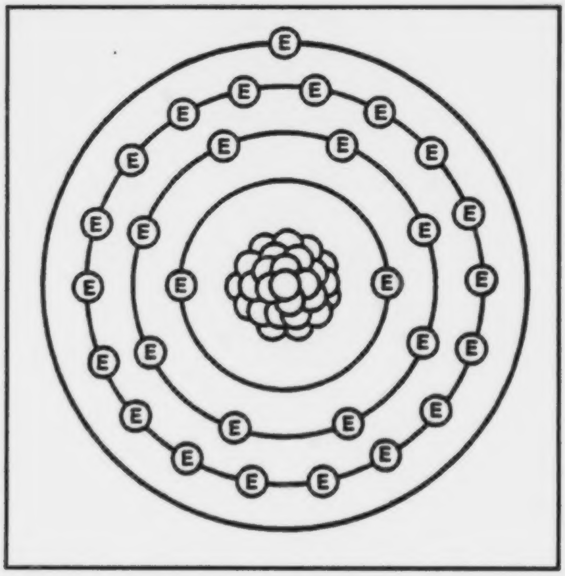

Fig. 1. A copper atom (Courtesy of General Motors Corp.)

The fewer the electrons contained in the outer orbit, the easier it is for the atom to share or give up these electrons. *Electricity* is the flow of electrons. Only material that will give up its electrons can be a conductor of electricity. Since only the outer orbit of an atom is involved in the movement of electrons, a *conductor* can be defined as an atom with *3 or fewer electrons* in its outer orbit. Remember that a full outer orbit has 8 electrons. Materials with *4 electrons* in their outer orbits are considered *semiconductors*. Elements with *5 or more electrons* in the outer orbit are *insulators*. The best insulating material has 8 electrons in the outer orbit.

All metals are good conductors. Silver is the best conductor, with copper close behind it with one electron in the outer orbit. Copper is generally used to make wire and printed circuit board conductors because it is much cheaper than silver.

Remember that *the flow of electricity requires the movement of electrons from atom to atom.* Atoms with more electrons in their outer orbit will not conduct as readily as the metals. Carbon has 4 electrons in its outer orbit and is considered a semiconductor. Insulators have a larger number of electrons in their outer orbits. An insulator will not allow its electrons to move, so electricity cannot flow.

Electricity

Before automotive technicians can properly diagnose the complex electronics in the modern automobile, they have to understand how electricity works.

Rubbing amber with fur causes the amber to become negatively charged. *"Negatively charged" means it has an excess of electrons.*

When a glass rod is rubbed with silk, the glass becomes positively charged. *This means the glass has a deficiency of atoms* since some electrons have traveled from the glass to the silk. The silk will have an excess of electrons.

If two small particles have a negative charge, the two particles will repel each other. If one particle has a negative charge and the other has a positive charge, they will attract each other. If you take two plastic rods and charge them (see fig. 2), the unlike charges will attract each other, and the like charges will repel each other.

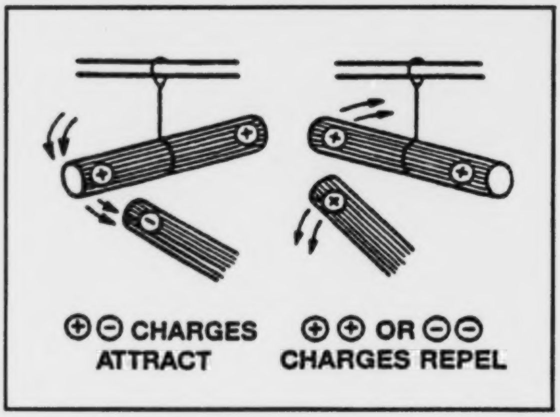

Fig. 2. Electrical charges (Courtesy of General Motors Corp.)

This is similar to the way the poles on two magnets react with each other. As the north poles of two magnets are brought close together, they repel each other. If the north pole on one magnet is brought close to the south pole on another magnet, they attract each other.

Experiment

You can experiment with positive and negative charges by tearing off some pieces of paper and putting them in front of you on your desk. Next, take a plastic pen or other plastic rod, and touch the pieces of paper. Unless a static charge has already been placed on the pen, nothing of interest will happen.

Now rub the plastic pen on your clothing, and try it again. Notice that the paper is attracted to the plastic pen. When you rubbed the pen on your clothes, you built up a static charge by moving some electrons. The static charge on the pen was different from the charge on the paper, and unlike charges attract.

A static charge does not involve a flow of electrons. The *static charge* results from an excess or a deficiency of electrons that are motionless. *Electric current* results from a flow of electrons. For electrons to flow, there must be a difference in potential. *A difference in potential will exist between a positively charged terminal and a negatively charged terminal.*

Figure 3 shows the momentary movement of electrons between two charged terminals. The electrons will only continue moving while the charges are unequal. Since there is nothing to create additional electrons to maintain the difference in potential, the flow will only last for a moment.

Like Charges Repel
Unlike Charges Attract

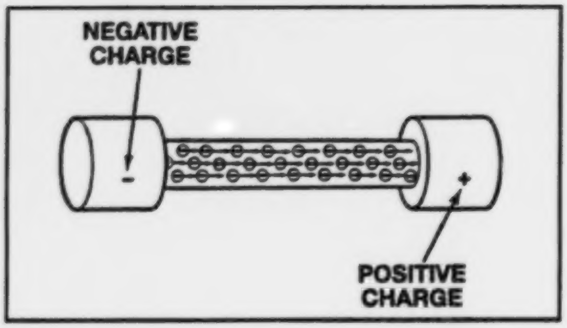

Fig. 3. Electrical charge action (Courtesy of General Motors Corp.)

Only an insulator can store an electrical charge. Before the electrons will move between two oppositely charged objects, there must be both *a difference in potential and a conducting path or circuit* for the electrons (fig. 4). *The difference in potential is the difference in charge or the difference in the level of an excess or a deficiency of electrons.*

The conducting path can be the objects touching or a conductor connected to the two terminals.

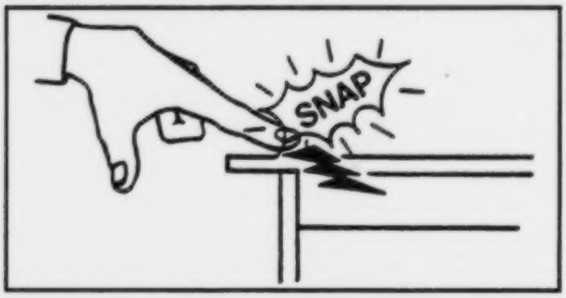

Fig. 4. Static discharge (Courtesy of General Motors Corp.)

Copper is a good conductor. The one electron in its outer orbit will easily move from one copper atom to another. When current flows through a piece of copper wire, electrons are pushed into one end of the wire. These electrons push the electrons already in the wire, causing the electrons at the other end of the wire to move.

It is a little like filling a tube with marbles and pushing extra marbles in one end of the tube. Since the electrons all have a similar negative charge, they will repel each other. This is shown in figure 5 as springs between the electrons. The extra marble pushed in at one end of the tube will cause the marble at the other end to fall out. Similarly, each electron pushing on the electron in front of it results in an almost instantaneous effect at the other end of the wire.

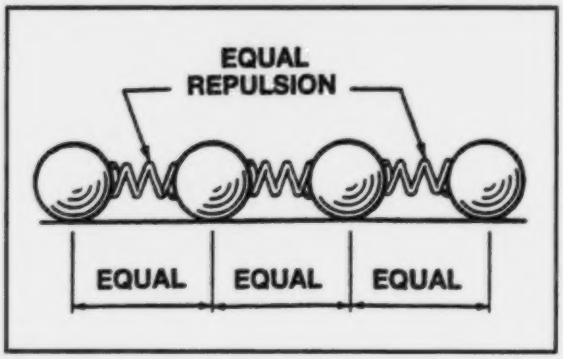

Fig. 5. Electron movement (Courtesy of General Motors Corp.)

Self-Test

Write short answers to each of the following questions. Check your answers with the answers at the end of this assignment.

1. Will two particles with different charges be attracted to each other or repel each other?
2. How many electrons will there be in a full L orbit of an atom?
3. In which orbit of a copper atom will the electrons have the most energy?
4. If energy is added to an atom causing an electron to move to a higher orbit, what happens when the electron falls back to its original orbit?
5. How many electrons are in a full outer orbit?

6. Which metal is considered the best conductor of electricity?

Voltage

A static charge exerts pressure on electrons and will cause the electrons to move if there is a conducting path. The unit used to measure this electrical pressure is called a **volt (V)**, in honor of Alessandro Volta (1745-1827). You use the word *voltage to describe the concept of electrical pressure* and the word *volt to describe the unit or amount of that pressure*. An older term for electrical pressure is *electromotive force (E)*. This term is still used, so you may see either a *V* for volts or an *E* for electromotive force in the figures to come. Both stand for the same pressure that moves electrons.

It is important to understand what voltage is. Voltage is simply the *pressure* on the electrons. If you put a pressure gauge on a water tank (see fig. 6), it will show the pressure of the water in it. This pressure would continue to exist with water moving in, or out of the tank or not moving at all.

Voltage behaves in the same way as the pressure of the water in the tank. An ordinary car battery will have 12 volts of pressure on the terminals when the battery is disconnected and sitting on a shelf. It will also have 12 volts when it is connected in the car and supplying electricity to a car radio.

Voltage is the potential difference between two points. If you take two 12V car batteries, connect their negative terminals, and measure the voltage between their positive terminals, you will see no potential difference or no voltage. With both terminals at a positive 12V, there is no difference between them and no voltage between the two positive terminals. If you connect the positive terminal of one battery to the negative terminal of the second battery, the voltage will be the sum of the voltages on each of the batteries, or 24V. By connecting the positive to the negative, you have added potential instead of canceling it out.

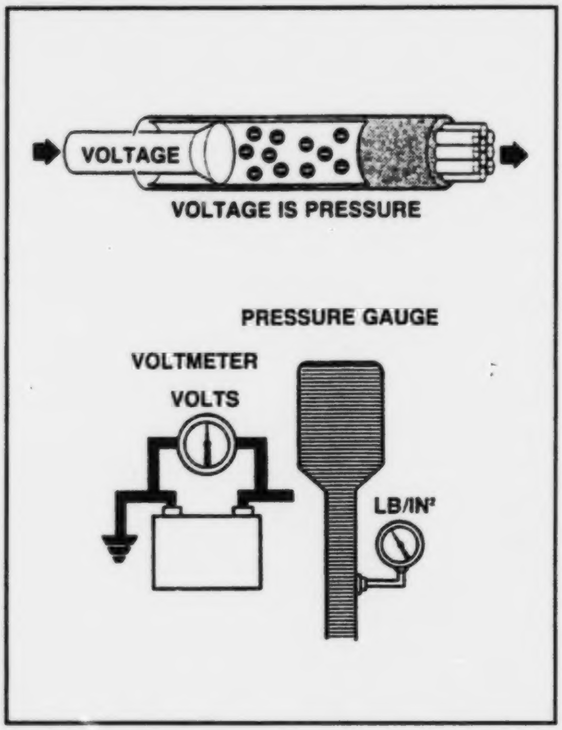

Fig. 6. Voltage equals pressure. (Courtesy of Toyota Motor Company)

The typical lead acid car battery is a storage battery that can be recharged. The electrons that come out of the battery when it is used can be replaced by charging the battery. A 12V car battery has 12V of pressure pushing the electrons out of the battery. To push electrons back into the battery, a voltage higher than the 12V is necessary. Remember that, although the 12V on the battery is trying to push the electrons out, they will not move unless there is a conducting path for them.

Current Flow

Voltage is the pressure that moves the electrons. When electrons are moving, all generally in the same direction through a conductor, it is called current flow. The abbreviation for current flow is the letter *I*. *Current flow is measured in amperes*, which you can abbreviate as *amp* or use the letter *A*. The term *ampere* is named after Andre M. Ampere (1775-1836).

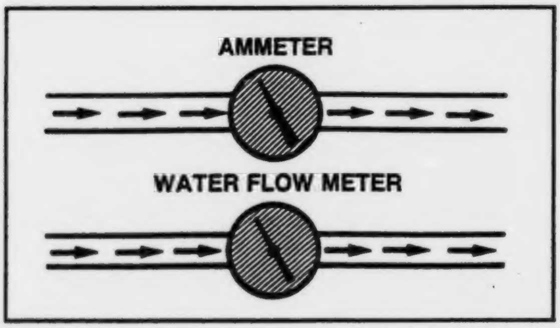

Fig. 7. Amperes equal current. (Courtesy of Toyota Motor Company)

One ampere of current is one coulomb of electrons passing a point in one second. Figure 7 shows how the flow of current in amperes is similar to the flow of water which could be measured in gallons per minute.

Resistance

The opposition to current flow is called resistance. The *unit of measurement for resistance is the ohm.* The letter *R is normally used for resistance,* and the Greek symbol *Ω is used for ohms.*

All materials have some resistance to the flow of current. Even a good conductor like a copper wire will have some resistance, which can be significant for large amounts of current or long runs of wire. An insulator will have a very large amount of resistance.

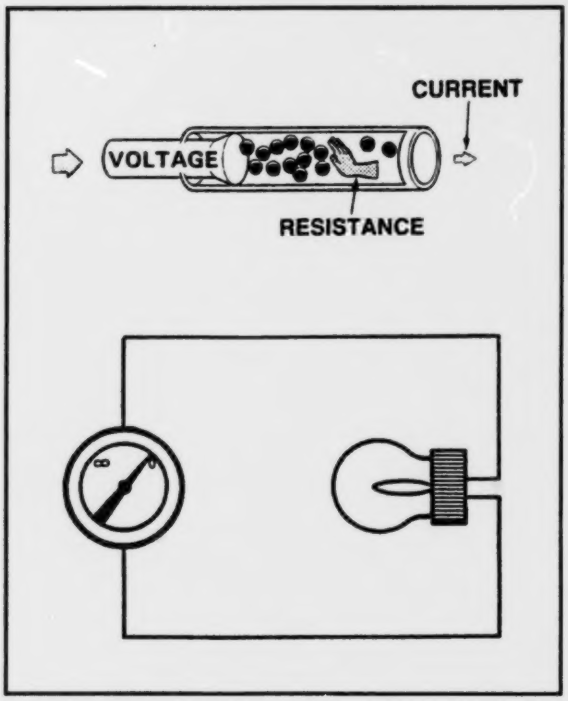

Fig. 8. All conductors offer resistance to current flow. (Courtesy of Toyota Motor Company)

Complete Circuit

A complete path or circuit must be available for current to flow. A circuit must take the electrons from one terminal through the circuit and back to the other terminal at the source of the current. Connecting a copper wire between the negative terminal of one battery and the positive terminal of another battery will not result in current flow.

If a copper wire is connected from the positive terminal of a battery to a switch and then to a lamp and back through a fuse to the negative terminal of a battery, as shown in figure 9, there is a complete circuit.

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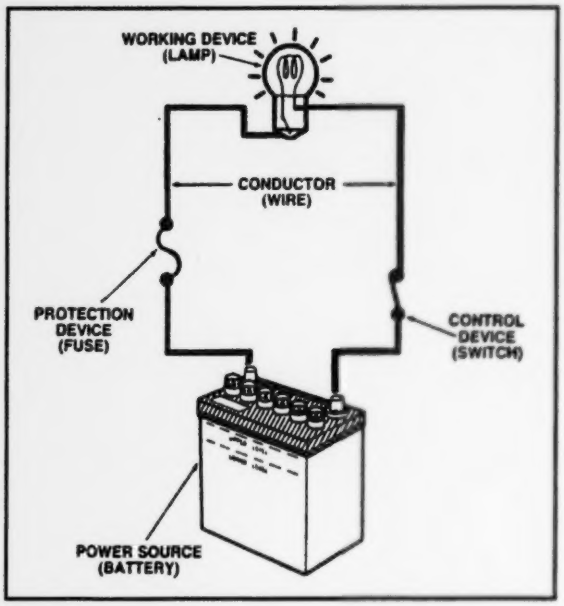


Fig. 9. A complete circuit (Courtesy of General Motors Corp.)

The electrons will move out of the negative terminal through the wire, the switch, lamp, and fuse, and back into the positive terminal. If one end of a copper wire is not connected to anything and the other end is connected to either terminal of a battery, there will be no current flow.

When a wire is connected to a circuit only at one end, the circuit is said to be "open." An *open* in a circuit can often be a break in a copper wire or the copper pattern on a circuit board. An open is the same as opening the switch in a circuit. The open switch stops all current flow past that point.

The amount of current in any closed circuit is the same everywhere in the circuit. A wire connected to the positive and negative terminals of a battery will have an equal amount of current flow everywhere in the length of the wire. A point in the wire that is close to the negative terminal will have the strong push from the negative terminal, and the point close to the positive terminal will have a strong pull on the electrons, but this will not change the fact that the current flow throughout the wire is the same. If there is one ampere of current in a wire, there is one ampere of current at all points in that wire. *Note:* this assumes that there are no wires branching off this wire in our example.

Conventional Current versus Electron Flow

The term *electron flow* describes the actual flow of electrons from the negative terminal of a voltage source to the positive terminal of the voltage source. Today most engineers and technicians use conventional current flow. *Conventional current flow theory assumes that electricity flows in the opposite direction to actual electron flow.*

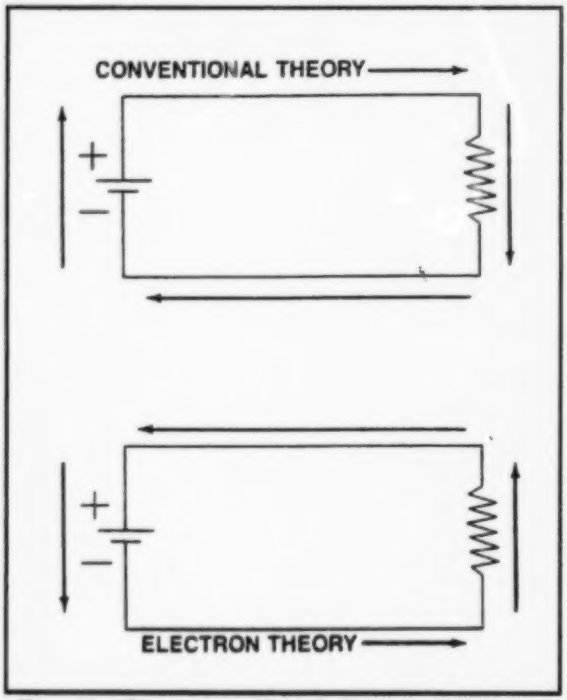


Fig. 10. Conventional and electron theories of current flow (Courtesy of General Motors Corp.)

Conventional current flow is used by almost everyone in the automotive industry because it allows you to work with positive numbers (fig. 10). The math becomes too cumbersome if you try to maintain the correctness of the electron flow. Also, the arrows that are part of the symbols for many electronic devices all show the flow of current as conventional current flow. We will use conventional current flow throughout this book.

Ohm's Law

Georg Simon Ohm first observed the relationship between voltage, current, and resistance in 1827. He found that if any one of the three—voltage, resistance, or current—were held constant, the other two would be directly proportional to each other.

You can express Ohm's findings in formula form, known as Ohm's law.

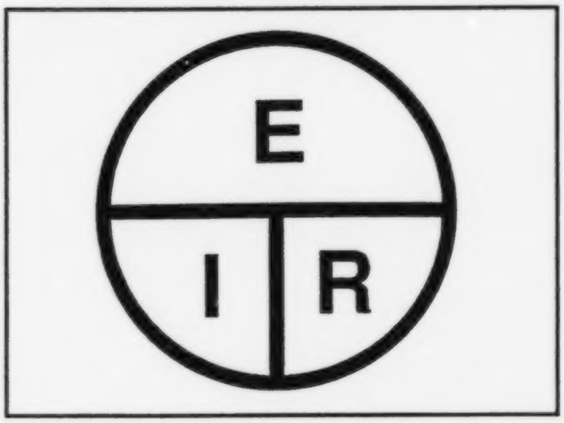


Fig. 11. Ohm's law diagram (Courtesy of General Motors Corp.)

The three forms of Ohm's law (fig. 11) use *E* for voltage in volts, *I* for current in amperes, and *R* for resistance in ohms or Ω.

The three forms of Ohm's law are:

$$E = IR,\ I = \frac{E}{R},\ \text{and}\ R = \frac{E}{I}.$$

These three formulas should be memorized by all students of electronics. The chart in figure 11 can be used to help you remember the formulas for Ohm's law. Figure 12 shows how you can use the chart to remember the formula for finding the current, figure 13 shows the formula for finding the resistance, and figure 14 shows how to find the voltage.

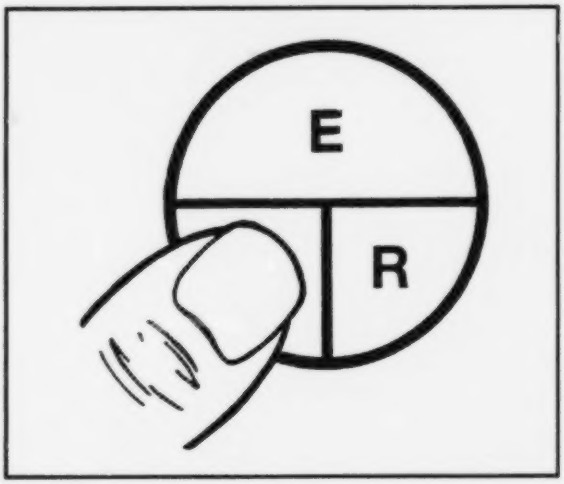


Fig. 12. Finding current or amperage (Courtesy of General Motors Corp.)

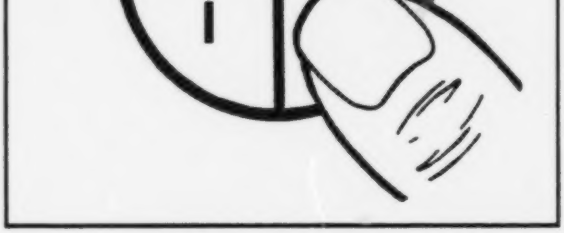


Fig. 13. Finding resistance (Courtesy of General Motors Corp.)

Automotive electronics, at the level it is now, is a relatively new phenomenon. Most of the electrical drawings in the automotive service literature resemble the drawings showing the fuel and water paths in the car. The complexity of the electronics in a typical car is forcing a change in the drawings, which should start to resemble electronic schematics. We will use electronic schematics often to help you become familiar with them.

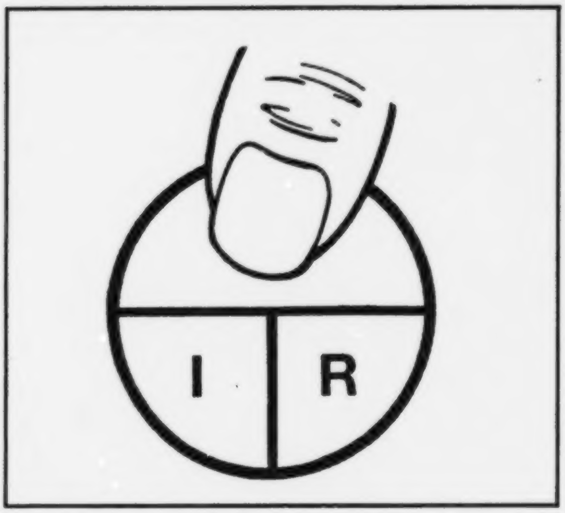


Fig. 14. Finding voltage (Courtesy of General Motors Corp.)

The electronic schematic in figure 15 shows a voltage source, which can be a battery, connected to a switch and the switch connected to a resistance. The *voltage source is the symbol consisting of two horizontal lines, with one line longer than the other*. The longer line represents the positive terminal of the voltage source. The voltage source symbol is usually only placed vertically, as shown in figure 15, although it can be placed horizontally.

Notice that polarity signs have been added to the voltage source symbol. The symbol below the voltage source and also below the resistance is the symbol for ground. In the case of an automobile, the ground would be the chassis of the automobile. The ground symbol is a common connection point, which means that all ground connections are connected together.

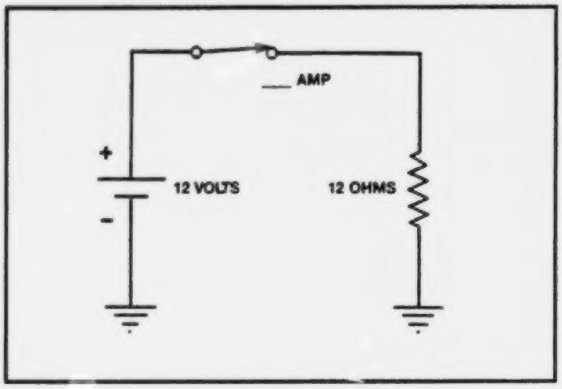


Fig. 15. Electronic schematic (Courtesy of General Motors Corp.)

The *arrow with circles at both ends is the symbol for a switch.* This switch symbol shows that it is connected. If the arrow is up and not touching the circle, it represents an open at that point.

The *jagged line represents a resistance*. The resistance in this drawing shows 12Ω. The resistance symbol can be either vertical or horizontal.

The voltage and resistance values are shown in figure 15, leaving just the circuit current as an unknown. The formula for finding current is:

$$I = \frac{E}{R}.$$

According to the formula, you divide the voltage, which is 12V, by the resistance, which is 12Ω, for a total of one amp (1A) of current.

Figure 16 shows same components with different values—the voltage is 12V and the current is 6A. You need to find the resistance. The Ohm's law formula for finding resistance is:

$$R = \frac{E}{I}.$$

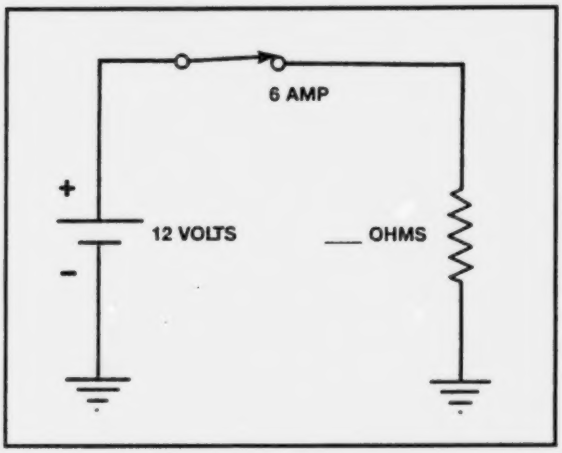


Fig. 16. Schematic to find the resistance (Courtesy of General Motors Corp.)

Dividing the voltage of 12V by the current of 6A gives 2Ω for the resistance.

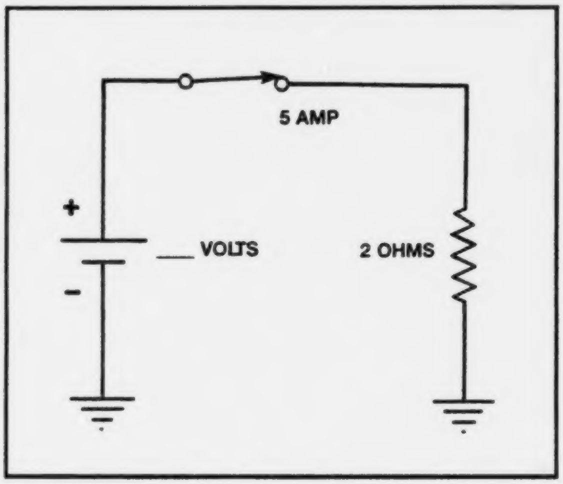


Fig. 17. Schematic to find the voltage (Courtesy of General Motors Corp.)

Figure 17 shows a schematic with values for the current and resistance. To find the voltage, you can refer to the formula, which is E = IR.

Multiplying the current of 5A times the resistance of 2Ω gives 10V for the voltage.

Summary

You have learned that electricity involves the electrons in the outer orbits of the material's atoms. When you have an excess or a deficiency of electrons, you have an electrical charge which is called voltage. The voltage is the pressure that will move electrons. We use both the letters *V* and *E* for voltage. The amount of voltage is measured in volts. The flow of electricity is the movement of these electrons and is called current flow. We measure current flow in amperes, which is abbreviated *amp* or just the letter *A*. The force that resists the flow of current is called resistance and is abbreviated *R*. We measure resistance in ohms and often use the Greek symbol Ω for ohms.

The formulas in Ohm's law define the relationship between voltage, current, and resistance. Ohm's law states that the voltage is equal to the current times the resistance. The current is equal to the voltage divided by the resistance, and the resistance is equal to the voltage divided by the current.

For current to flow in a circuit, there must be a complete circuit. If the circuit is broken either by a switch or an open, the current in the circuit will stop moving.

Current flow is the movement of electrons, which travel from the negative terminal to the positive terminal. This actual flow of electrons is called electron flow. Conventional current flow assumes that current flows from positive to negative to make it easier to work electrical math. We will use conventional current flow in this book.

Self-Test Answers

1. *Two particles with different charges will be attracted to each other. Like charges repel, and unlike charges attract.*
2. *The L orbit will have 8 electrons when it is full.*
3. *in the outer orbit, which has one electron*
4. *When an electron falls back to a lower orbit, it will give off energy in the form of light radiation.*
5. *Any full outer orbit will have only 8 electrons.*
6. *Silver is considered the best conductor of electricity, but because of cost, copper is usually used as a conductor in most circuits.*

Exercise

1. What is voltage?
2. What is an amp?
3. What is an ohm?
4. What are the three formulas for Ohm's law?
5. A 12V car battery is connected to a light with 25Ω of resistance. How much current is passing through the light?
6. Which metal has the best conductivity?
7. How much current will normally flow through an insulator before the voltage reaches breakdown?
8. In figure 18, if the voltage source is 15V and the resistance is 3Ω, what is the current in the circuit?
9. Assume that the circ.uit current in figure 18 is 2A and the voltage is 7V. What is the resistance?
10. A technician wants to replace the two headlights, which take 3A, with a resistor. The technician wants to use the resistor instead of the lamps to avoid the heat and light generated when testing a 12V battery. What size resistor should the technician use?
11. If figure 18 has a resistance of 4Ω and circuit current of 2A, what is the voltage?

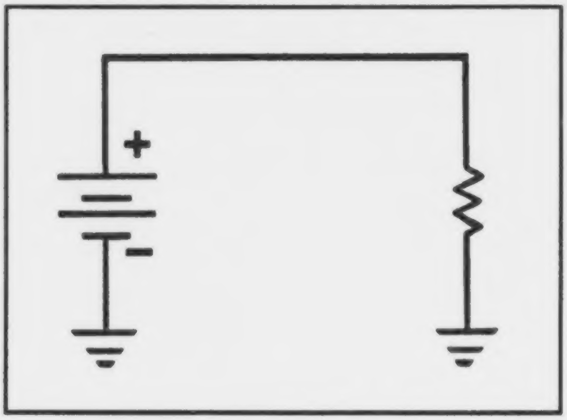


Fig. 18. (Courtesy of General Motors Corp.)

C-2

Circuit Analysis

Essential Elements: (gg)(1-3)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain the difference between series and parallel circuits*
- *explain how to use a digital meter*

Scientific Notation

Some of the sensors on the automobile will cause shifts in current, voltage, and resistance that are only small fractions of one unit. Many of the resistance values that you will work with are in very large units. For example, only a few thousandths of an ampere of current may pass through many sensors; however, they may have over 100,000 ohms of resistance.

A number like 34,000,000 is very large and has six zeros after the significant part of the number. There is an easier way to write numbers without all of the zeros either behind large whole numbers or in front of small fractional numbers. By using *scientific notation,* we can abbreviate these numbers. For instance, the 34,000,000 above can be expressed as 34^6. If you count the zeros from the right to the left beginning with tens, hundreds, thousands, ten thousands, hundred thousands, and millions, you can see that 34 multiplied by one million equals 34,000.000. Thus, 34,000,000 can be expressed as 34^6.

When we show multiplication in arithmetic, we normally use the small letter x. In algebra, using the letter x can cause confusion; therefore, it is standard practice to use a centered dot to show multiplication. We will generally use the dot method to show multiplication in this manual.

The standard form for scientific notation requires that you place only one digit to the left of the decimal point. This number is then multiplied by the correct power of 10. The number 12,600 can be expressed as $1.26 \cdot 10^4$, for example. When dealing with electronics, it is often not convenient to use only one digit to the left of the decimal point.

Rounding Off Numbers

If you multiply $64.8 \cdot 10^5$ times 29.6. 10^3 on a good scientific calculator, you will get $1.91808 \cdot 10^{11}$. The result has 6 significant digits in the answer. The two numbers you multiplied had only three significant digits. You answer cannot have a greater accuracy than the numbers you used to compute the answer. The $1.91808 \cdot 10^{11}$ should be rounded off to three significant digits. This would give us $1.92 \cdot 10^{11}$. When rounding off a number, increase the last digit if the number following is 5 or greater. For example, 3.4999 would remain 3 if rounded to one digit and 3.5000 would become 4 when rounded to one digit.

Electronic Notation

The units used in electronics are often very large or very small. It is usually more convenient to use these units with a prefix to indicate the power of 10 multiplier. You are probably already familiar with the use of *k* for kilo in kilometer, which means meters times 10^3. The ohm, which is a common unit of resistance, can have the prefix *k* in front of it. The prefix *k* will indicate the unit is multiplied by 10^3. 1.2k ohms or 1.2 kΩ is 1,200Ω. The uppercase letter *M* indicates that the unit is multiplied by one hundred thousand; 2.5MHz is 25,000,000Hz.

The lowercase letter *m* for milli indicates the unit is multiplied by 10^{-3}. 1.2mΩ is 0.0012Ω. A special symbol is used for micro, which means 10^{-6}. This symbol is *μ*. The number 1.2μΩ is 0.0000012Ω. The following chart will list some commonly used prefixes in electronics.

In the list of symbols, if a lower-case letter is indicated, a capital letter would be wrong. Notice that both a lowercase *m* and a capital *M* are used. The letter *k* for kilo is sometimes used as a capital letter. We will use it as a lowercase letter in this course.

Power of 10	Prefix	Symbol
10^6	mega	M
10^3	kilo	k
10^{-3}	milli	m
10^{-6}	micro	μ

Notice that the list of prefixes does not cover every power of ten. It is for this reason that we cannot follow the rule of scientific notation. A component with 12,000Ω will either be 12kΩ or 0.012MΩ. We would usually call it 12kΩ.

Series and Parallel Circuits

A *series circuit* can be defined as a circuit in which all the current flows through all the components in the circuit. As a result, the current is the same throughout the circuit. A *parallel circuit* causes the current to branch through the individual parallel branches.

The schematic in figure 1 shows a series circuit with two resistors or loads. Notice that there is only one path. Figure 2 shows two resistors or loads in parallel, giving the current two paths to follow. A way to test whether components are in parallel or in series is to look at how they are connected together. Two or more components in parallel will all be connected together at both ends, while components in series are only connected together at one end.

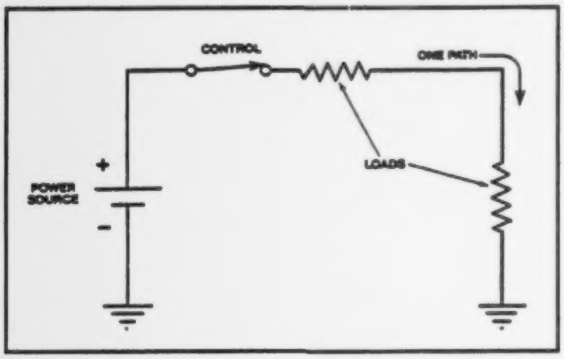


Fig. 1. Series circuit diagram. (Courtesy of General Motors Corp.)

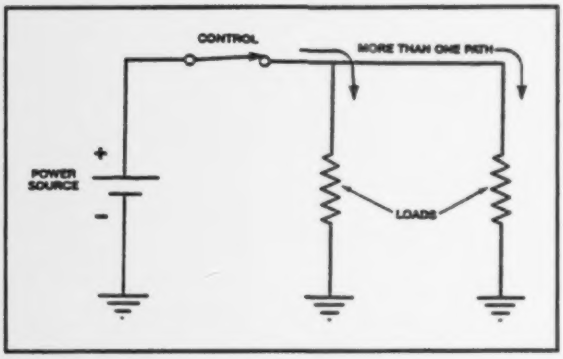


Fig. 2. Parallel circuit diagram. (Courtesy of General Motors Corp.)

The total resistance of the series circuit can be found by adding the individual resistances. If the power source in figure 1 is 12V and the first resistor is 1.2 kΩ and the other resistor is 2.4kΩ, then the total resistance is 1.2k plus 2.4k, which will equal 3.6kΩ. The total current for the circuit can now be found by dividing the power source voltage of 12V by the total resistance of 3.6kΩ. This gives 3.33mA of current.

Finding the total resistance for the parallel circuit is a little more complicated than finding the total resistance for a series circuit. The easiest way to find the total resistance is to use the following formula, which you should memorize.

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}}$$

This formula is very easy to use with a calculator that has a "1/X" function on it. Simply use the 1/X function to invert the resistance and add it to the next inverted resistance. When you have added all of the inverted resistances, then invert the result for the final parallel circuit resistance.

Series-Parallel Circuit Analysis

The series-parallel circuits that you will see in a typical automobile will have the car battery for the voltage source, some components in series with the source and each other, and some in parallel. Figures 3A and 3B show a simplified view of two common possibilities for series-parallel circuits.

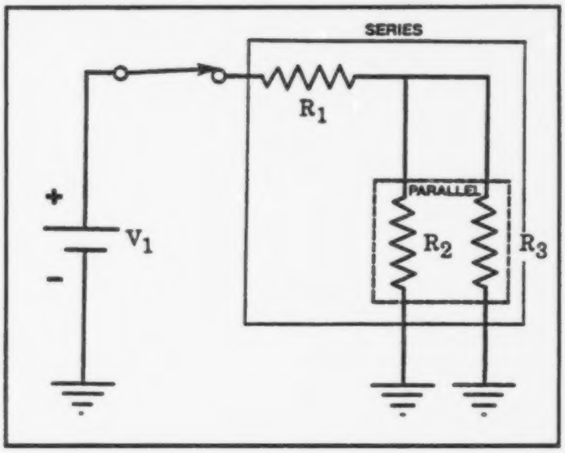


Fig. 3A. Type of series-parallel circuit

In figure 3A, notice that R_2 and R_3 are in parallel. Also, notice that the combination of R_2 and R_3 is in series with R_1.

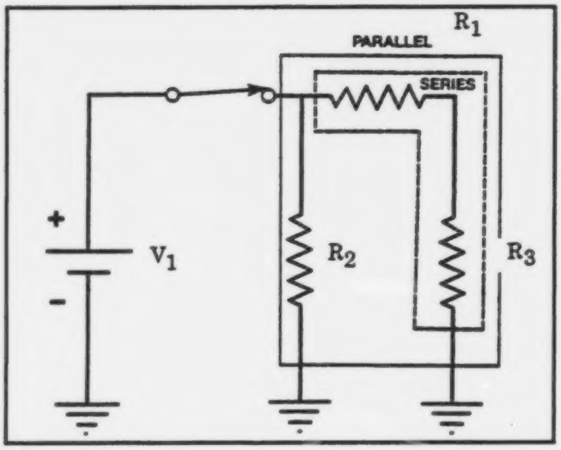


Fig. 3B. Type of series-parallel circuit. (Courtesy of General Motors Corp.)

If resistor R_2 has a value of 1.2kΩ and R_3 a value of 2.4kΩ, you can calculate the parallel equivalent resistance for these two parallel resistors. Working it out on the calculator, we come up with 0.8kΩ or 800Ω resistance for the parallel circuit.

This 800Ω for the parallel combination of R_2 and R_3 is in series with R_1. If R_1 has a value of 3.6kΩ, you can combine the parallel value of 800Ω with R_1. When resistors are in series, you simply add the resistances, which is 800 plus 3,600, or 0.8 plus 3.6 for a total of 4.4kΩ.

This 4.4kΩ is the combined equivalent resistance for the circuit. If V_1 is 12V, then the circuit current, according to Ohm's law, will be the 12V divided by the 4.4kΩ. This gives 2.727272, or rounding it off gives us 2.73mA of current.

You can use the same values for figure 3B and find the circuit current. Notice that R_1 and R_3 are in series and that R_3 is not in parallel with R_2. The series combination of R_1 and R_3 is in parallel with R_2. When resistors are in series, simply add their values. Therefore, R_1 and R_3 equal 3.6 plus 2.4 or 6kΩ. This 6kΩ is in parallel with R_2 or the 1.2kΩ resistance. Combining these values in parallel gives 1kΩ for the total circuit resistance. Using Ohm's law to find the current results in 12V divided by 1kΩ, or 12mA of current.

Now, go back and look at what happens when the 2.73mA of current passes through the resistors in figure 3A. When the current leaves the voltage source, it first passes through resistor R_1.

This 2.73mA of current passing through a 3.6kΩ resistor, according to Ohm's law, should give a 9.8V drop across the resistor. Remember that you started with 12V from the source and have now dropped 9.8V of it across this first resistor. This leaves 12V minus 9.8V, or 2.2V across the parallel resistors. Since R_2 and R_3 are in parallel, the voltage drop across each of them will be the same, 2.2V.

Notice that in figure 3A the voltage drops across the resistors add up to the voltage from the source. The polarity of the voltage across each resistor will be the opposite of the polarity across the voltage source. You can use this information to find the voltage drop across an unknown component when you know the voltage drops in the rest of the circuit.

Self-Test

Check your answers with the answers at the end of this assignment.

1. For the following, write the number using ordinary scientific notation (one digit to the left of the decimal point).
   a. 1.2kΩ b. 13.5mA c. 12ns
   d. 7.6MΩ e. 325μA f. 15pF
   g. 14GHz h. 0.014mV i. 1450mV

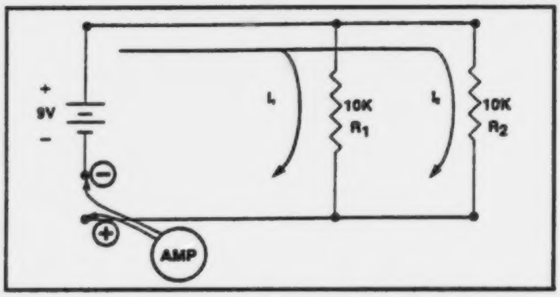


Fig. 4. Parallel Circuit (Courtesy of General Motors Corp.)

2. Figure 4 shows a voltage source and two 10kΩ resistors in parallel. The circuit is open with an illustration showing where to put an ammeter. Assume that you do not have an ammeter and put a 100Ω resistor in that place instead. What will the voltage drop across this 100Ω resistor be?

Meters

The basic meter that is used to measure voltage, resistance, and current is the most important piece of test equipment for an automotive technician. The analog meter, with a pointer movement instead of a digital readout, uses the current available in the measurement to give a reading in volts, ohms, or amperes. This type of meter is often called a *VOM* for volt-ohmmeter.

This meter movement, as shown in figure 5, uses a permanent magnet to put a strong magnetic field on a movable coil. The small movable coil is connected to the pointer that moves across the face of the scale. The movable coil and pointer move in proportion to the amount of current passed through the coil.

A meter needs only a small amount of current to move the pointer full scale, or all the way across the face of the meter. The amount of current necessary for full-scale deflection of the pointer can be from 50mA to 30mA. Additional circuitry inside the meter protects the meter and allows the instrument to measure voltage, current, and resistance at many different levels.

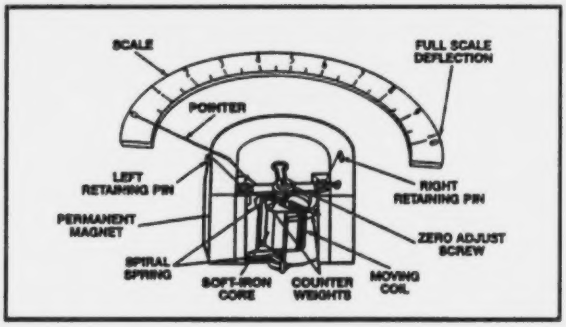


Fig. 5. Meter movement details. (Courtesy of General Motors Corp.)

Digital Meters

The modern state-of-the-art digital meter that measures only volts and ohms, called a *DVOM,* is generally far superior to all but the most expensive analog meters. A digital meter with functions for measuring voltage, resistance, and in some cases current, as well as checking diodes and other functions, is called a digital multimeter or *DMM*. The DMM in figure 5 is a typical low-cost meter that was manufactured using an integrated circuit specifically designed for DMMs. We will use the familiar term *DVOM* in this text.

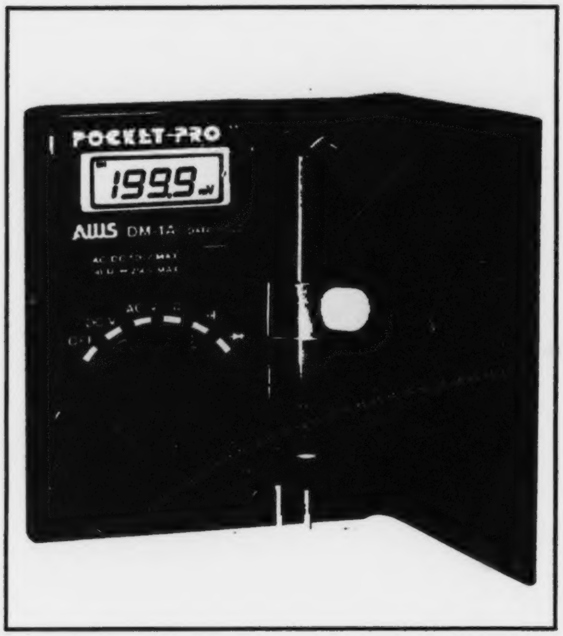


Fig. 6. Digital Multimeter (Courtesy of A.W. Sperry Instruments, Inc.)

When the multimeter shown in figure 6 changes ranges, the decimal point moves to the appropriate location. This has become a common feature on digital multimeters. This meter also has a button for holding the display when the probes are removed. This will allow you to take a reading, remove the meter, and then read it.

Many meters of this type have a range button that will lock in the range and turn off the automatic ranging. Locking in the range can speed up the time the meter takes to settle down and give a reading.

Digital Meter Accuracy

The manufacturer will often state the accuracy of its meter as a combination of two numbers. The accuracy of the DVOM in figure 6, according to A. W. Sperry Instrument Inc., for voltage readings only is (1.0% rdg + 4d). This means the voltage indicated on the display is within 1.0% of the true voltage and the indicated voltage is within 4 digits of the true voltage. A reading of 100.0V on the instrument could be 1.0% off or 1V off and 4 digits or 0.4V off from the true voltage. The combination of these two potential errors gives a potential error of 1.4V. The true voltage could be from 98.6V to 101.4V. This is effectively an accuracy of 1.4% compared to a good analog instrument which would be 2%.

DVOM Construction

Measuring voltages which are analog in nature and converting them to the digital numbers displayed on the instrument is the basic task of a DVOM. The two most common methods of doing this are called the successive trials and the voltage-to-frequency system. The *voltage-to-frequency method* converts the dc voltage to a series of pulses. The higher the voltage, the more pulses per second. A counter will count the number of pulses within a time period and display the voltage on the screen.

The *successive trials method* compares the input dc voltage with a voltage that is generated in the instrument. The generated voltage is changed in steps until the generated voltage matches the input voltage. The system used to generate the voltage also results in a code which is used to put the value of the voltage on the display.

Both of these measuring systems require the meter to take samples of the voltage and display the value of the voltage in that sample. If the instrument is slow in taking samples, it may take longer to settle down and give a valid reading.

When a DVOM is used to measure ac voltages, the instrument will convert the ac to dc and process the voltage in the same manner as the dc voltage. Two methods are used to convert the ac to dc. The better method is called the *true rms method* and will give a better reading for ac signals that are not good sine waves. The other method is called *averaging*, and is good for only clean sine waves.

If the DVOM has the capability of measuring current, it will have a small value resistor inside the meter and will take the voltage drop across the resistor when the current is run through the meter. It uses this method for both ac and dc current measurements. The voltage drop is then handled like a voltage measurement and displayed on the meter as current. Some meters have an accessory that measures the magnetic effect of ac current using a probe and displays the value of the current in the wire without actually making contact with the wire.

A DVOM can usually measure resistance from a few ohms to tens of megohms. The instrument provides a small voltage—usually 0.3V or less—and reads the voltage drop across its internal resistor. The current flow will depend on the value of the resistance being measured, and the smaller the resistance under test, the greater the voltage drop across the internal resistance. If there is any voltage in the circuit when a resistance reading is taken, the circuit voltage will affect the reading and give erroneous results.

The small voltage of 0.3V is not enough to push current through diodes and transistors. This allows the DVOM to test resistors in the circuit if they are isolated by diodes and transistors. It also avoids turning transistors on and creating problems with large flows of current.

When a diode or transistor needs to be tested, the DVOM will often have a diode test function that has a higher voltage to push the current through the device. Some of the more expensive meters provide a constant level of current in the diode test function and display the voltage drop when testing the diode or transistor.

Self-Test Answers

1. a. *1.2kΩ* $1.2 \cdot 10^{-3}$
   b. *13.5mA* $1.35 \cdot 10^{-2}$
   c. *12ns* $1.2 \cdot 10^{-8}$
   d. *7.6MΩ* $7.6 \cdot 10^{6}$
   e. *325mA* $3.25 \cdot 10^{-4}$
   f. *15pF* $1.5 \cdot 10^{-11}$
   g. *14GHz1* $4 \cdot \backslash 10^{-8}$
   h *0.014mV* $1.4 \cdot 10^{-5}$
   i. *1450mV* $1.45 \cdot 10^{0}$ *or 1.45*
2. *The two parallel 10kΩ resistors will combine to a 5kΩ which is in series with the 100Ω. This gives 5,100Ω total resistance. The 9V divided by the 5,100Ω gives 1.76mA circuit current. The 1.76mA circuit current times the 100Ω resistor gives the voltage drop across this resistor, which is 176mV.*

Summary

In automotive electronics, the most common electronic prefixes that you will probably encounter are the *k* for kilo, *m* for milli, and *μ* for micro. The *k* stands for 10^{3}, the *m* for 10^{-3}, and the *μ* stands for 10^{-6}. You can often find the current by dividing 12 volts or some other voltage close to this by a resistance in kΩ. When you divide a whole number by a number with the

10^{-3}, as you will do when dividing volts by kΩ, the result will be in mA. Remembering this can make many of your computations easier.

In a circuit with resistors in series, the combined resistance for the circuit can be found by adding the resistors in series. When the resistors are in parallel, you must use a more complicated formula, which should be memorized:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}}$$

This formula is best used on a scientific calculator. Notice that in any parallel circuit, the combined resistance will always be less than the branch with the lowest value of resistance. Also, if the resistances in parallel are equal, the combined resistance can be found by dividing the value of one of the resistances by the number of resistances in parallel.

Some of the older analog meters and test lamps can damage the sensitive computer circuits in the modern automobile. It is better for the automotive technician to use a good DVOM, or digital multimeter, which will have a high input impedance. Impedance is the combined resistance or the total input resistance of the meter. Most DVOMs currently available are very accurate and reliable. Some technicians will use the range hold function of their DVOM to speed up the measurements.

Exercise

1. When measuring the resistance of a resistor in the circuit, what should you do about the voltage source?
2. If a DVOM with an accuracy specification of (2.0% + 2d) shows a reading of 20.4V, what is the range of possible true voltages?
3. How much current in μA will there be if the circuit has 1.2kV and 24MΩ?
4. Insert a 150Ω resistor in the place marked "AMP" in figure 7 and find the voltage drop across this 150Ω resistor.

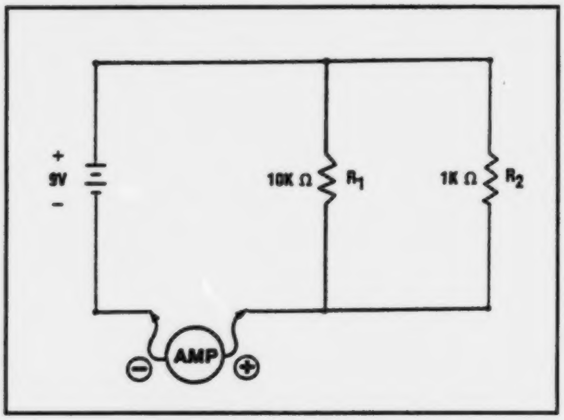


Fig. 7. Parallel circuit.
(Courtesy of General Motors Corp.)

5. If R_1 burned out leaving an open, in figure 7, what would be the voltage drop across the 150Ω resistor from question 4?
6. In figure 7, if a short developed across R_2, what would be the voltage drop across the 150Ω resistor from question 4?
7. In figure 7, if a short were placed in the space marked "AMP," how much current would pass through R_2?
8. In figure 7, if the voltage source is changed to 12V and a 1.2kΩ resistor is placed in the spot marked "AMP," what would the total circuit current be?

C-2 Circuit Analysis

Laboratory Experiment

Essential Elements: (gg) (1-3)

Objectives

This lab will be used to test your computations and determine if your math is correct when you analyze a circuit. You will start by analyzing each circuit, record all of your results, then build the circuit, and measure it. When you compare the calculated results with the measured results, you will be able to confirm the accuracy of your calculations.

Equipment

1	battery holder for four dry cell batteries
4	dry cell batteries
1	package of 10 jumper leads with alligator clips
1	DVOM
1	470Ω 5% resistor (Colors Yellow, Violet, Brown, and Gold)
1	1000Ω 5% resistor (Colors Brown, Black, Red, and Gold)
1	2.2kΩ 5% resistor (Colors Red, Red, Red, and Gold)
1	4.7kΩ 5% resistor (Colors Yellow, Violet, Red, and Gold)

Procedures

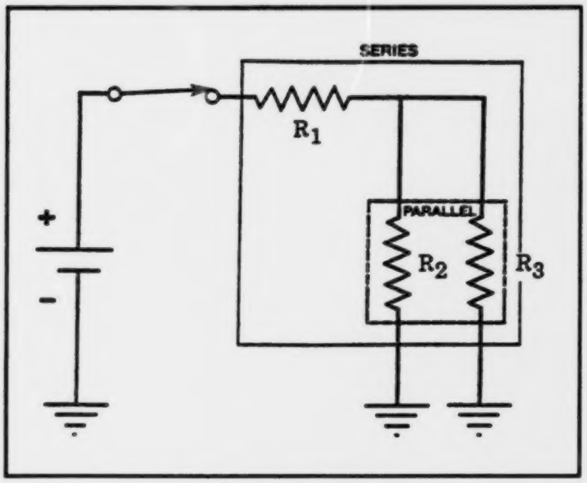


Figure 1

The four dry cell batteries in this lab will provide 6V. If this arrangement providing 6V is not available or the resistors you have chosen are not available, use components that are as close as possible, and have the instructor check the accuracy of your calculations.

In figure 1, use the 6V for V_1, the 2.2kΩ for R_1, 1000Ω for R_2, and the 470Ω for R_3.

1. Calculate the resistance for the parallel combination of R_2 and R_3. Record this value, and leave space next to it for the measured value.
2. Calculate the total circuit resistance, and record this value. Leave space for the measured value.
3. Calculate the total current for the circuit in figure 1, and record your answer.
4. Calculate the voltage drop across each resistor, and record this voltage drop, leaving space on your paper for the measured voltage drop.
5. When all the calculated values are recorded, record the color code values of all the resistors. Next, use the resistance function of your digital meter to measure the resistance of the four resistors. Record these values next to the color code values. The measured values should be within 5% of the color code values.
6. Use the jumpers to connect R_2 and R_3 in parallel. Measure the combined parallel resistance, and record it next to your measured value. Recheck your calculations if there is a difference of more than 10% between the measured and calculated values.
7. Use an additional jumper to connect R_1 to the parallel resistors, and measure the total resistance for the circuit. Record this value, and compare it with the calculated resistance. If there is more than a 10% difference, recheck your calculations.
8. Insert the batteries into the battery holder, and use the jumpers to connect the battery pack to the resistors. Measure the voltage drop across each resistor, and record these values.

   The measured values will be lower than the calculated values if the battery voltage is lower than the 6V used for calculations. Adjust the expected measured values downward based on the battery voltage. Also, the total of the voltage measured across R_1 plus the voltage measured across R_2 or R_3 should equal the actual battery voltage.
9. Use Ohm's law to find the total circuit current by dividing the voltage drop across R_1 by the resistance of R_1. Compare the measured values with the

calculated values. The difference should not be more than 10%, provided your battery voltage is close to the 6V that you used for the calculations.

Watch the battery voltage again. The measured current will be lower with a lower battery voltage. The current should be within 10% if the battery voltage is close.

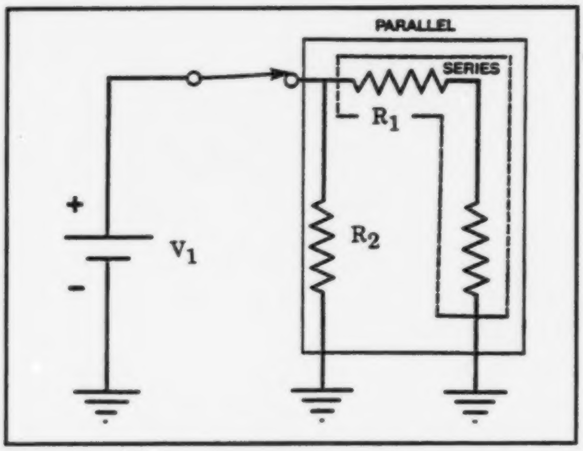


Figure 2

In figure 2, use the 6V for V_1, the 4.7kΩ for R_1, 2.2kΩ for R_2, and the 1,000Ω for R_3.

10. Calculate the resistance of the series combination of R_1 and R_3. Record this value, and leave space next to it for the measured value.

11. Calculate the total circuit resistance, and record this value. Leave space for the measured value.

12. Calculate the total current for the circuit in figure 2, and record your answer.

13. Calculate the voltage drop across each resistor, and record this voltage drop, leaving space on your paper for the measured voltage drop.

14. Use the jumpers to connect R_1 and R_3, and measure the series resistance. Record this value, and compare it with the calculated values.

15. Connect R_2 and measure the total circuit resistance, and record and compare this value with the calculated values.

16. Finally, connect the battery pack to the circuit, and measure and record all voltages.

The measured voltages should be within 10% of the following calculated voltages except for the lower battery voltage. Adjust the expected measured voltages down for lower battery voltages.

17. Use the measured voltage drops across R_1 and R_2 divided by their resistances to find the current. Add these two currents for the total circuit current, and record and compare this value with the calculated values.

C-3

Conductors and Resistors

Essential Elements: (gg)(1-3)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

Specific Objectives:

After completing this assignment, you will be able to:

- *read the resistance of color-coded resistors*
- *explain how to repair damaged wire*
- *explain how to repair connectors*

Resistors

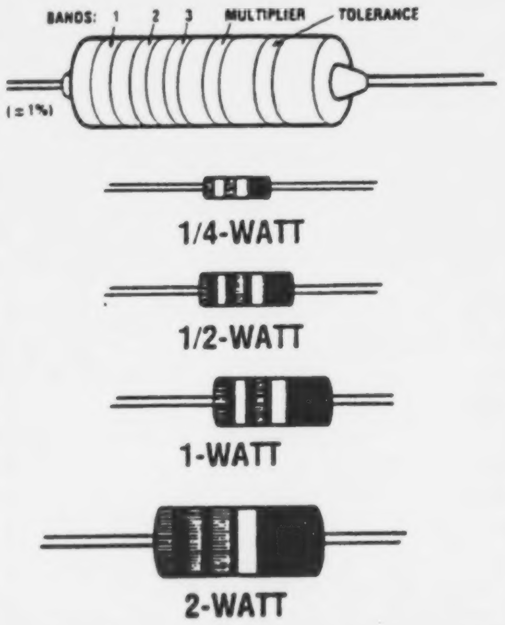
Two basic types of resistors are commonly found in automotive applications—the *fixed value* resistor and the *variable* resistor.

The fixed value resistor may be made from a mixture of carbon and clay, or it may be the carbon film type, which has a coating of carbon around a ceramic rod. The amount of carbon in both types will determine the amount of resistance. Another common fixed value resistor is made from resistance wire and enclosed in ceramic material.

The fixed value resistor is usually a small cylinder with the wire leads coming out of each end. The resistors designed to handle large current loads are usually made from resistance wire and have the value written on the side of the resistor. The carbon types of fixed value resistors usually use a color code to identify their value, as shown in figure 1.

The system of color coding resistors gives us three possible tolerances based on the fourth color band. No color or no band is a 20% tolerance, silver is 10%, gold is 5%, and brown is 1%. A 5% tolerance means the actual resistance can be up to 5% different than the resistance value shown by the other three color code bands.

Many years ago, when tubes were still used in electronic equipment, the 10% and 20% tolerance resistors were popular. Today, the demands of solid-state electronics require at least the 5% tolerance resistors. As a result, it is hard to find 10% or 20% resistors.



BAND 1 1ST DIGIT		BAND 2 2ND DIGIT		BAND 3 (IF USED) 3RD DIGIT	
COLOR	DIGIT	COLOR	DIGIT	COLOR	DIGIT
BLACK	0	BLACK	0	BLACK	0
BROWN	1	BROWN	1	BROWN	1
RED	2	RED	2	RED	2
ORANGE	3	ORANGE	3	ORANGE	3
YELLOW	4	YELLOW	4	YELLOW	4
GREEN	5	GREEN	5	GREEN	5
BLUE	6	BLUE	6	BLUE	6
VIOLET	7	VIOLET	7	VIOLET	7
GRAY	8	GRAY	8	GRAY	8
WHITE	9	WHITE	9	WHITE	9

MULTIPLIER	
COLOR	MULTIPLIER
BLACK	1
BROWN	10
RED	100
ORANGE	1.000
YELLOW	10.000
GREEN	100.000
BLUE	1.000.000
SILVER	0.01
GOLD	0.1

RESISTANCE TOLERANCE	
COLOR	TOLERANCE
SILVER	± 10%
GOLD	± 5%
BROWN	± 1%

Fig. 1. Fixed resistors with color codes. (Courtesy of Toyota)

In your lab experiments, you have used the standard carbon fixed value resistors with the color codes. Most of the circuit boards in the computer modules on most automobiles have very few, if any, resistors. The integrated circuits will have resistive components inside them. Some resistors designed to handle large amounts of power are located throughout the automobile. These resistors are generally wire-wound with the values printed on them.

We have only included the color codes in figure 1 to help you with the laboratory. Your resistors will probably only have three color bands and the gold 5% tolerance band. To read the value of the resistor, start with the color band that is farthest from the gold band. Look at the chart, and write down the number for this first color band. Next, write down the number for the second band next to it. Now multiply this two-digit number that you have written down times the number from the third band, which is the multiplier. This gives the resistance value for that resistor.

The typical automobile will have many variable resistors. In the early days of electricity, a variable resistor was used to control large amounts of power such as dimming stage lights. These early variable resistors were called *rheostats*. The variable resistors used to control the volume of a typical radio are called *potentiometers*. From this early application, the definition of a rheostat is a variable resistor that controls power, and a potentiometer controls signal or small amounts of current. Another definition states that the rheostat has only two leads coming off it, and the potentiometer has three.

There is no clear separation between the terms *rheostat* and *poten-*

tiometer. Potentiometer is a more modern term, and we will use it for all variable resistors of this type. A potentiometer, abbreviated as "pot," can be made from resistance wire or carbon deposited on a ceramic base. The wire type will generally be used to control the speed of fan motors, and the carbon type will be used as a volume control. You should avoid mixing applications since the wire type will handle much more power than the carbon type. The problem with the wire type is that the change in resistance jumps as the wiper is moved over the resistance wires. This jumping as the control is turned will create noise in a radio. The carbon type will change resistance smoothly but cannot handle any power.

Figure 2 shows a typical pot used for a car radio. This pot can have a linear taper or a logarithmic taper. The linear taper changes resistance at the same rate that the control is turned. The logarithmic taper will change at a faster rate than the rate the control is turned. This logarithmic taper is used for the primary volume control since it matches our ears' response to audio volume.

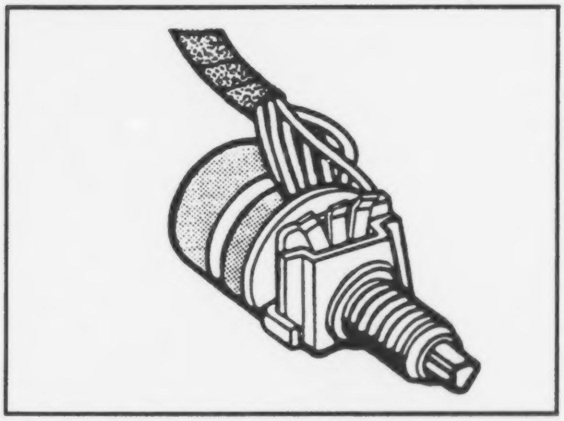


Fig. 2. A potentiometer. (Courtesy of Toyota)

The *thermistor* could fall into either the fixed or variable resistance category. This resistor is a fixed resistor which changes its resistance with temperature. It is normally used as a sensor; for example, most water temperature sensors are now thermistors instead of the bimetallic type.

The thermistor will change its resistance value either increasing with an increase in temperature (positive temperature coefficient) or decreasing with an increase in temperature (negative temperature coefficient). You will normally only see this type of resistor as a sensor encapsulated in a housing designed to be screwed into the side of the engine or mounted near the water pump.

Electrical Wire

Sometimes the wiring harness will be moved and routed through an area that the manufacturer had not intended. When this happens, the wires can be damaged from heat melting the insulation or sharp metal cutting through the insulation. If this happens, it will be necessary to repair the broken or damaged part of the wiring harness.

If the damaged wire is in a part of the harness that is taped, care must be taken not to damage the insulation of the other wires when pulling the tape off to separate the wires. When the damaged wire is free of the harness, remove the damaged area by cutting the wire. Once the damaged area on the wire is removed, there may be enough slack to splice the wire. If there is not enough wire to make a splice, then another short piece of the same size wire should be spliced into the break.

If more than one wire is damaged in the harness, it is important to make the splice on one wire at least 1 1/2 inches away from the splice on an adjacent wire. The splice should also be 1 1/2 inches away from all harness branches and connectors.

The following steps should be taken when repairing damaged copper wire by splicing. *Note:* some manufacturers are using aluminum wire for some applications. This type of wire requires special handling.

1. Open the harness, and remove the damaged wire or wires. If only the insulation is damaged, the spot can be taped and put back into the harness. If the copper wire has been damaged or broken, then the damaged part must be removed.

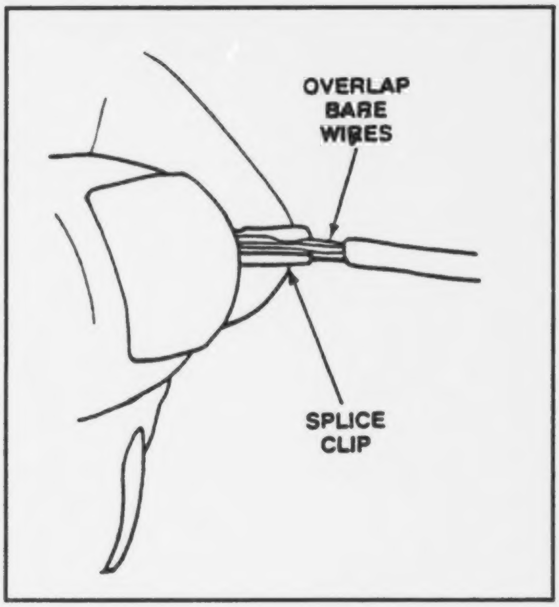

OVERLAP
BARE
WIRES
SPLICE
CLIP

Fig. 3. Centering the splice.
(Courtesy of General Motors Corp.)

2. Cut the wire at the damaged spot or, if necessary, cut away the damaged area. Remember that if more than one wire is damaged, your cuts will need to end up with splices at least 1 1/2 inches apart.

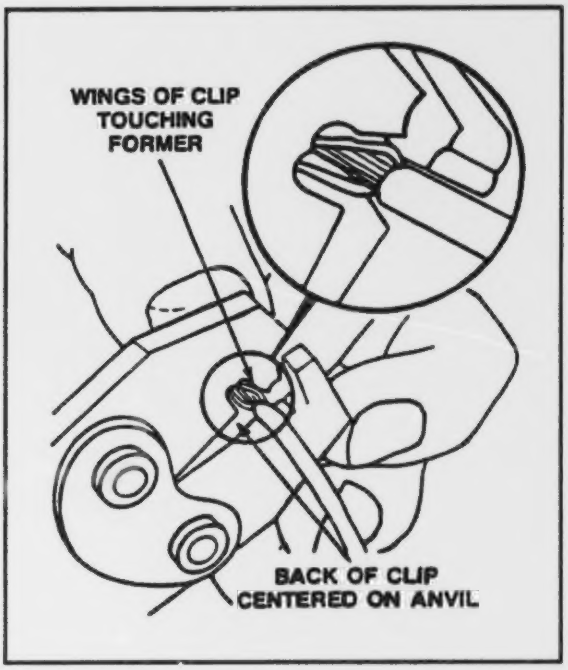

WINGS OF CLIP
TOUCHING
FORMER
BACK OF CLIP
CENTERED ON ANVIL

Fig. 4. Crimping the splice clip.
(Courtesy of General Motors Corp.)

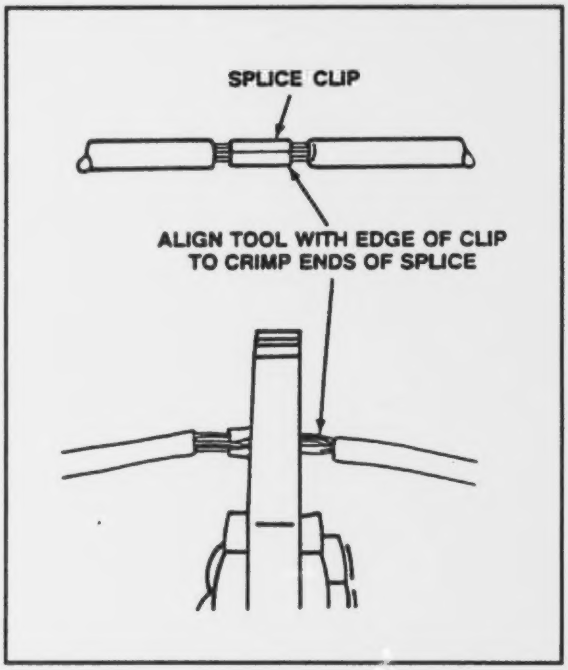

SPLICE CLIP
ALIGN TOOL WITH EDGE OF CLIP
TO CRIMP ENDS OF SPLICE

Fig. 5. Completing the crimp.
(Courtesy of General Motors Corp.)

3. If it is necessary, cut pieces of new wire to splice into the harness from wire that is the same size or larger. The replacement wire should also have insulation that is suitable for the automotive environment.

4. Use a wire stripper to remove about 1/3 inch of insulation from both ends of the wire to be added and each end of the original wire. Check the wire for any sign of nicks or cuts, which will weaken the wire and add resistance to the wire.

5. Obtain the proper clip for the size of the wire being spliced, and place the clip, overlapping the two wires as shown in figure 3. Center the clip, and hold it as shown.

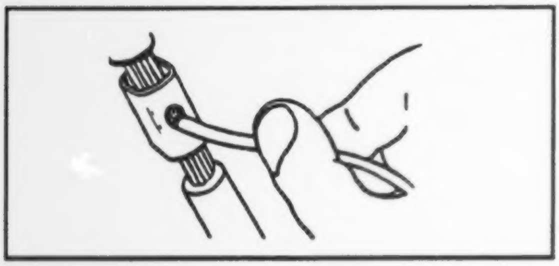


Fig. 6. Applying the solder. (Courtesy of General Motors Corp.)

6. Crimp the splice on both ends, watching that you do not damage the wire (see figs. 5 and 6).

7. Next solder the splice, as shown in figure 6. Use 60/40 solder with a rosin core. Do not use acid core solder. Acid core solder will eat away at your connection and destroy it in a few weeks.

8. Use good electrical tape to tape the connection. Start by unrolling some of the tape from the roll. Hold one end of the tape on the splice, and gently pull the tape as you wrap it around the splice. This will end up with a tight fit and avoid the loose end or flag (see fig. 7). Wrap enough tape to provide about the same thickness as the original insulation.

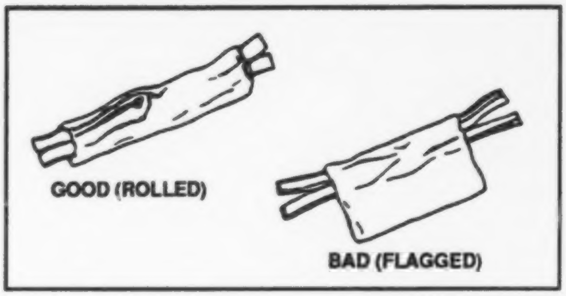


Fig. 7. Proper first taping. (Courtesy of General Motors Corp.)

9. Take another short piece of tape, and roll this piece of tape over the existing tape (see fig. 8). Then place the wire back into the harness.

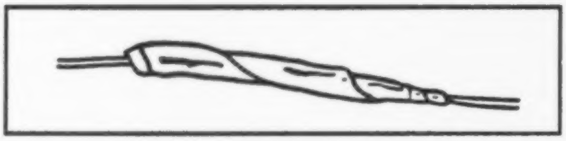


Fig. 8. Proper second taping. (Courtesy of General Motors Corp.)

Aluminum Wire

Some manufacturers are using aluminum wire to carry larger amounts of current. Aluminum wire saves on cost and weight of the automobile. Do not use the materials that you will normally use with copper wire to splice aluminum wire.

When aluminum comes in contact with copper or any other metal, galvanic corrosion will result. This corrosion will soon destroy the connection. Also, aluminum behaves differently under stress than copper and will come lose from a crimped splice. Special kits are available from the manufacturer to handle repairs on its aluminum wire.

Fusible Links

A fusible link is designed to burn out and protect the wire harness when there is excessive current in the wire. Fusible links are used in place of fuses. A fusible link is a short piece of wire that is four wire gauge sizes smaller than the wire it protects. It will have its wire size printed on the insulation (fig. 9) since the thick insulation on fusible links tends to make the wire look larger than it is.

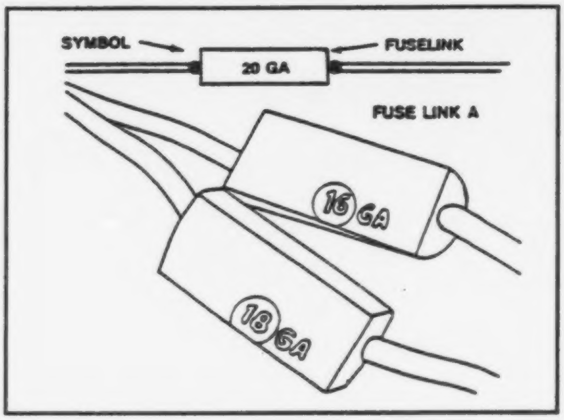


Fig. 9. Fusible links.
(Courtesy of Ford Motor Company)

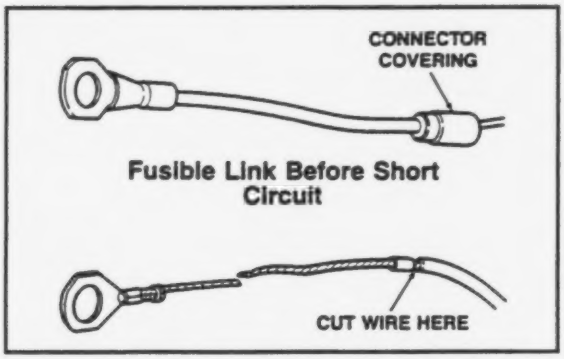


Fig. 10. Fusible link before and after short circuit. (Courtesy of General Motors Corp.)

When replacing a fusible link, it is important to use a link with the same type of insulation as the original.

Fusible link wire often comes in rolls. To replace a burned out link (see fig. 10), cut a short piece from the roll, and splice it to the harness wire or large size wire. Do not splice a piece of fusible link into an existing link. *Note:* when cutting a length of fusible link, do not cut a length longer than 9 inches. A longer fusible link will not provide proper protection to the wire harness.

Other Fuses

In addition to fusible links, there are three other types of fuse protection for the wiring and circuitry in an automobile. One has the fuse mounted in a glass cylinder with metal caps at both ends, and the newer flat type is made of plastic (fig. 11). These fuses are designed to open the circuit quickly when the current exceeds their rating.

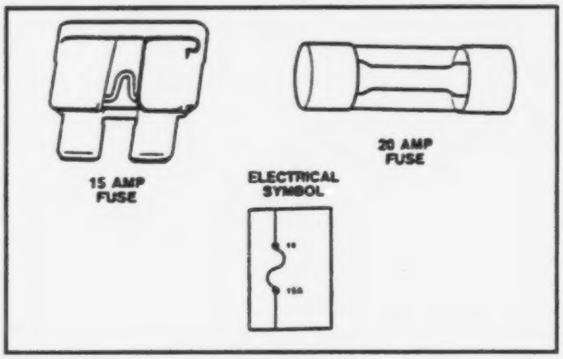


Fig. 11. Fuses.
(Courtesy of Ford Motor Company)

Once a fuse is blown, it has to be replaced. The circuit breaker (fig. 12), is also used to fuse a circuit, but does not have to be replaced. Some circuit breakers have to be manually reset after they open the circuit, and some will reset automatically.

Connectors

Over time, connectors can become loose, cracked, or broken. Automobile manufacturers use a large variety of connectors on their wiring harnesses. Most of these connectors have certain common characteristics.

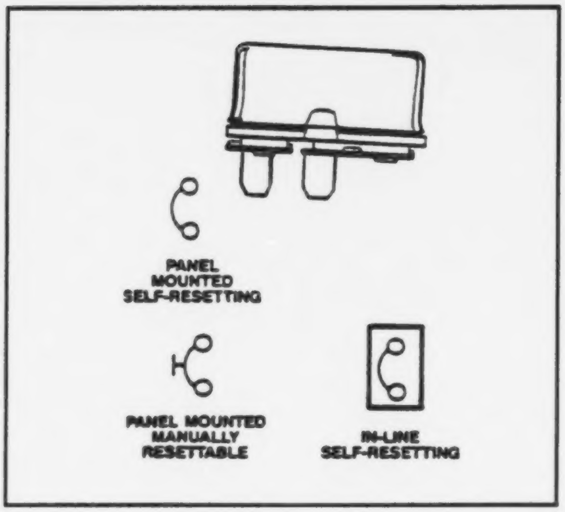

PANEL MOUNTED SELF-RESETTING
PANEL MOUNTED MANUALLY RESETTABLE
IN-LINE SELF-RESETTING

Fig. 12. Circuit breaker. (Courtesy of Ford Motor Company)

If a molded connector has a bad terminal that cannot be removed, the connector can be bypassed (fig. 13).

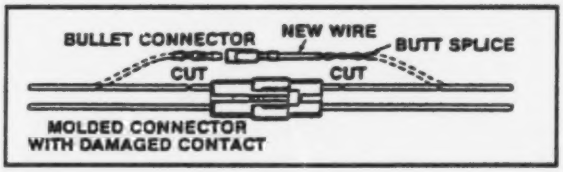

BULLET CONNECTOR
NEW WIRE
BUTT SPLICE
CUT
CUT
MOLDED CONNECTOR WITH DAMAGED CONTACT

Fig. 13. Bypassing a molded connection with a bullet connector (Courtesy of Ford Motor Company)

Use the crimping techniques that you have already learned to connect the bullet connector into the wire.

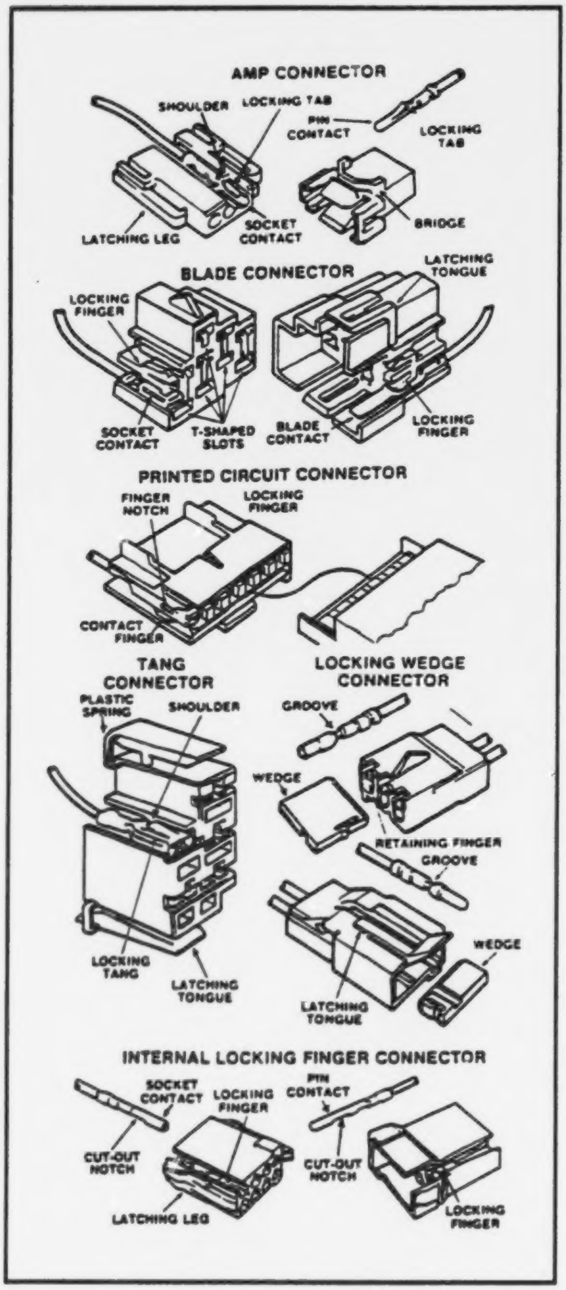

AMP CONNECTOR
SHOULDER
LOCKING TAB
PIN CONTACT
LOCKING TAB
LATCHING LEG
SOCKET CONTACT
BRIDGE
BLADE CONNECTOR
LATCHING TONGUE
LOCKING FINGER
SOCKET CONTACT
T-SHAPED SLOTS
BLADE CONTACT
LOCKING FINGER
PRINTED CIRCUIT CONNECTOR
FINGER NOTCH
LOCKING FINGER
CONTACT FINGER
TANG CONNECTOR
PLASTIC SPRING
SHOULDER
LOCKING TANG
LATCHING TONGUE
LOCKING WEDGE CONNECTOR
GROOVE
WEDGE
RETAINING FINGER
GROOVE
WEDGE
LATCHING TONGUE
INTERNAL LOCKING FINGER CONNECTOR
SOCKET CONTACT
LOCKING FINGER
PIN CONTACT
CUT-OUT NOTCH
CUT-OUT NOTCH
LATCHING LEG
LOCKING FINGER

Fig. 14. Six types of hard-shell connectors. (Courtesy of Ford Motor Company)

The connectors in figure 14 are called ***hard-shell connectors***, and all have terminals that can be replaced. If these connector shells show signs of burning, melting, or cracking, they should be replaced. The terminals should be replaced if they are loose, burnt, distorted, or corroded.

The following steps should be taken to replace a connector terminal.

1. Remove the terminal from the connector. For some connectors, a special tool will help to release the locking finger holding the terminal.
2. Next, cut the wire close to the old terminal. If all of the terminals are being replaced, you should mark the wires to avoid getting them mixed up when you reassemble the connector.
3. When the terminal is assembled to the wire, the wire should extend about 1/16 inch into the head of the terminal. The insulation should be past the insulation tabs shown in figure 15. Note that the insulation does not extend into the second tabs. Use a terminal to measure the length of strip that is necessary before stripping the wire. The correct strip length will make a neat job. Use the correct tool to strip the wire.

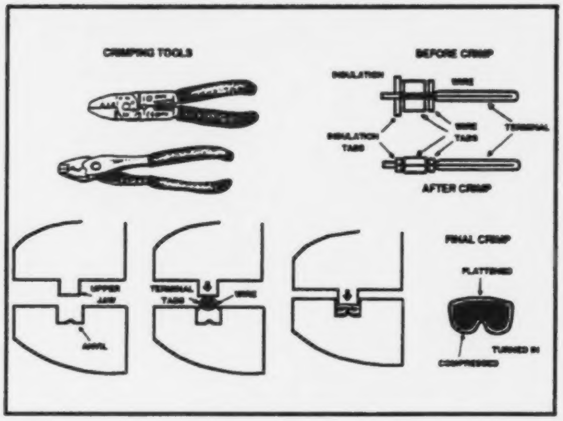


Fig. 15. Connector terminal crimps. (Courtesy of Ford Motor Company)

4. Next, crimp the tabs around the wire (fig. 15). The tabs should be tight around the insulation to keep the insulation from moving when the wire is pulled. Test the terminal by pulling on the wire. The wire should not show any signs of being loose. A resistance check should show no resistance between the terminal and the wire.
5. Insert the terminal into the connector, and check that it seats properly.

Another popular type of connector is the *amp-type connector*. These connectors have a bridge on the pin half of the connector and latching legs on the socket half of the connector, as shown in figure 16.

The terminal pins and sockets are held in the connectors by locking tabs. To replace either a pin or a socket, first separate the connector by squeezing the tabs on each side. With the connector opened up, take the following steps to replace either a socket or a pin.

1. There is a special tool that is designed to release the locking tab on the pins and sockets. Push this tool into the mating end of the pin or socket.
2. Apply pressure to the wire, pushing it into the connector to push the locking tab away from the plastic, and release it.
3. Next push in the tool, and rotate it to force the locking tab into the pin or socket.

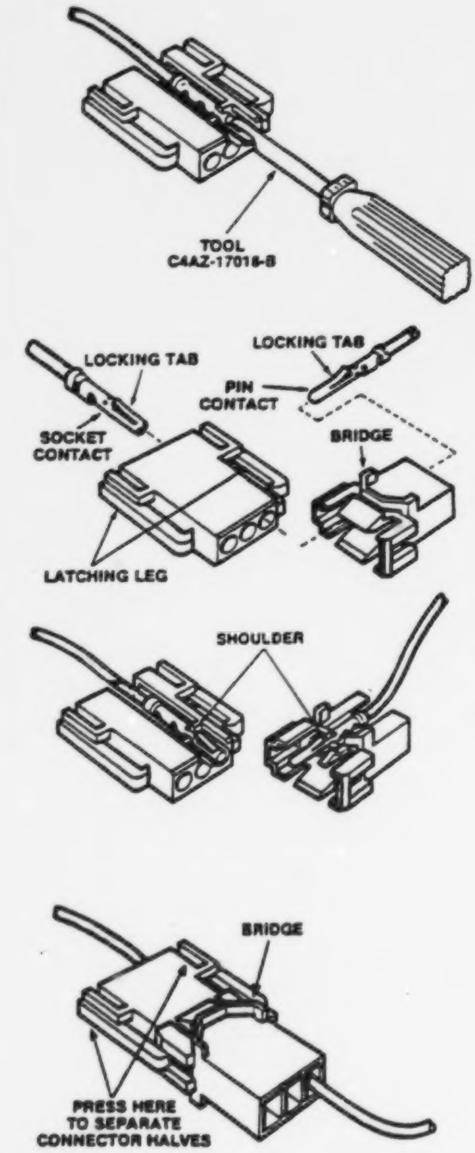


Fig. 16. Amp-type connectors. (Courtesy of Ford Motor Co.)

4. Finally, pull on the wire to remove the pin or socket.
5. Use the crimping techniques described earlier to replace the pin or socket, and then push the new pin or socket back into the connector.

(Do the optional laboratory experiment at this point if you have the equipment and supplies.)

Summary

Two broad categories of resistors are used in automotive applications. They are the fixed value resistor and the variable resistor. The fixed value resistors used on circuit boards are becoming so small that they will have no visible markings on them. The resistors found throughout the automobile are usually wire-wound and have the resistance value printed on them. Some of the resistors on some automobiles will have color codes like the resistors that you use in your lab.

The variable resistors are used for volume controls on radios and tape decks, and for light dimmers and other variable control applications. We call these variable resistors potentiometers, or just “pot.” A pot can be made from resistance wire or carbon deposited on a ceramic base. The resistance wire type handles more power, but is too noisy for use as a volume control on a radio. The carbon type is used for the volume control.

When you find that part of the wiring harness has been damaged, it is often possible to remove the damaged area and splice the wire back or add some additional wire if the final length of wire is not sufficient. The splices should never be made so they lie next to each other. All splices should be at least 1 1/2 inches apart and also 1 1/2 inches from all connectors and branches in the harness.

After the damaged area is removed, the wire should be reconnected. Each wire should be stripped, and a clip crimped on to the two wires holding them together. Then the connection should be soldered and taped.

Connectors can sometimes give problems. The terminals can become loose or damaged, and the shell can become damaged. There are special tools to help in removing the terminals from the connector when they have to be changed. It is important to always do a neat professional job when working with wire and connectors.

Exercise

1. Write in the resistance value for the following resistor color codes:
   a. Brown, Black, and Red
   b. Yellow, Violet, and Brown
   c. Red, Red, and Orange
   d. Red, Black, and Yellow
2. What kind of resistor will decrease its resistance when the temperature increases?
3. Which type of pot would be used to control a fan motor that draws a lot of current?
4. What problem would be caused by splicing a copper wire to an aluminum wire?
5. How far should a splice be from other splices, connectors, and branches in the harness?
6. What wire gauge of fusible link would you use to connect with a particular wire gauge of harness wire?
7. If the terminal in a connector is damaged and is not designed to be removed, how can you repair it without replacing the whole connector?

C-3 Conductors and Resistors

Laboratory Experiment (Optional)

Essential Elements: (gg) (1-3)

Objectives

In this lab, the student will practice repairing wire. Although soldering is not included in this lab, your instructor may add soldering if the equipment and facilities are available.

Equipment

3 feet of insulated wire
6 clips (the size of the clips should match the wire size)
1 roll of electrical tape
1 crimping tool (*Note:* if the crimping tool does not include a feature for cutting the wire and stripping the insulation, additional tools will be necessary.)

Procedure

1. Cut the wire into six pieces. Strip both ends of each piece of wire.

2. Use the techniques described in the assignment to crimp all six pieces of wire together to form a complete loop.

3. Tape the crimp connections.

4. Cut one of the pieces of wire in the loop, strip the insulation, and use the DVOM to test the resistance of the loop. There should be no significant resistance in the loop. If there is resistance, make some additional cuts in other sections to locate the faulty connection. If you find a faulty connection, examine it, and determine what you did wrong to cause the resistance. By examining your error, you can avoid making the same mistake again.

C-4

Magnetism

Essential Elements: (gg)(1-3)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how magnetism works*
- *build an electromagnet*
- *explain how a solenoid works*

The Magnetic Field

In very early times, people found pieces of iron ore called lodestone which are natural magnets. The early Chinese used pieces of lodestone to make a directional compass. Today we know that the earth is one large magnet (fig. 1) and that other magnets when allowed to move freely will align themselves with the earth.

The magnet's ability to align itself with the earth resulted in labeling the magnet with north and south poles. This started as the "north-seeking pole" and "south-seeking pole" (fig. 2).

A magnet's ability to attract another magnet or another piece of iron is its field of attraction. The field of attraction can be represented as lines of force. It is assumed that these lines of

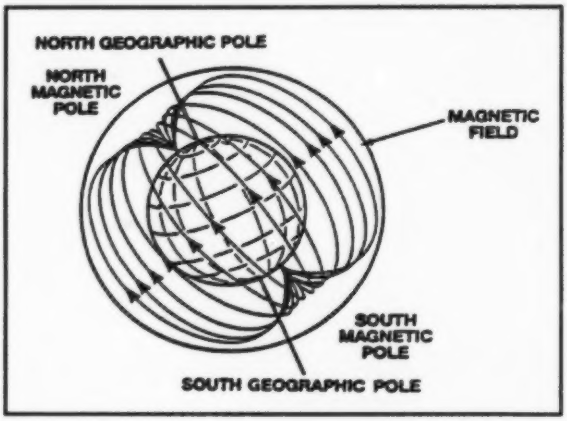


Fig. 1. Magnetic field of the earth. (Courtesy of General Motors Corp.)

force leave the north pole of a magnet and enter the south pole (fig. 3). We use the word "assumed," as we think about the mistake that Ben Franklin made when he labeled the direction of current flow.

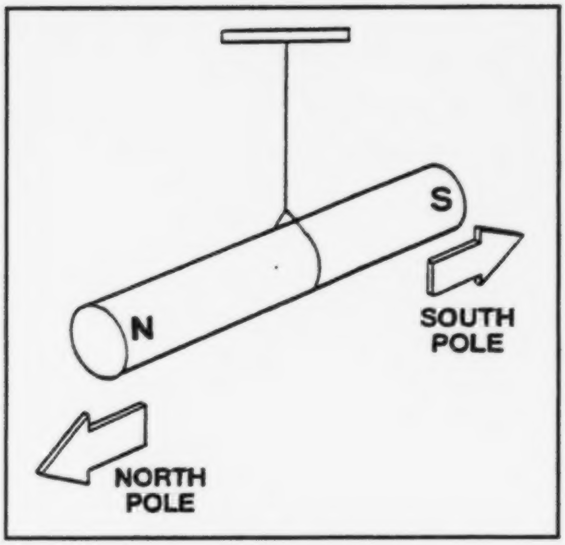


Fig. 2. Compass action.
(Courtesy of General Motors Corp.)

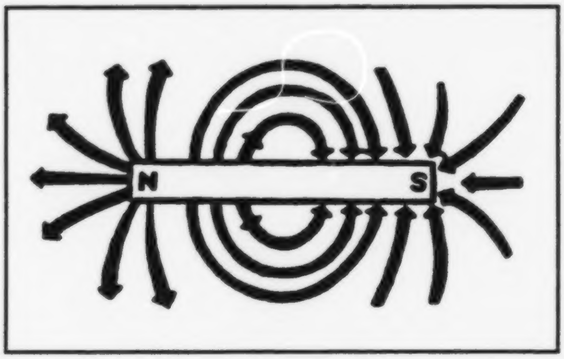


Fig. 3. Lines of force.
(Courtesy of General Motors Corp.)

These lines of force will be heavily concentrated near the poles on a bar magnet and weaker in the middle of the magnet (fig. 4). The lines of force are called *magnetic flux.* Magnetic flux is important in understanding how magnets create electricity.

When the poles of two magnets are brought close together, if the poles are the same polarity, the poles will repel each other. If the poles that are brought together are different in their polarity, they will attract each other (fig. 5).

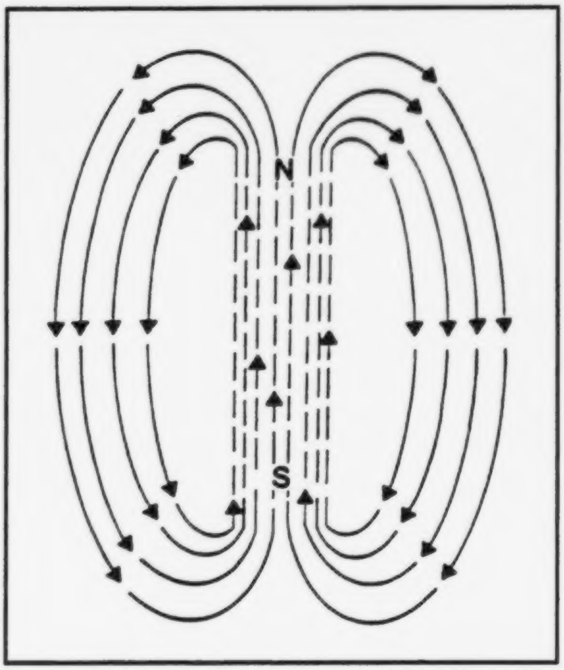


Fig. 4. Concentration of force.
(Courtesy of General Motors Corp.)

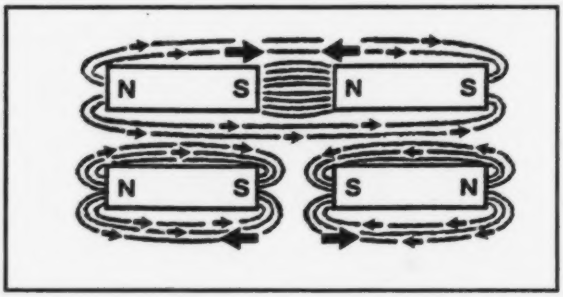


Fig. 5. Unlike poles attract; like poles repel.
(Courtesy of General Motors Corp.)

One method of explaining how a magnet works is by looking at each atom as if it were a small magnet inside the bar magnet. When the bar is not magnetized, all of the atom magnets are pointed in random directions (fig. 6).

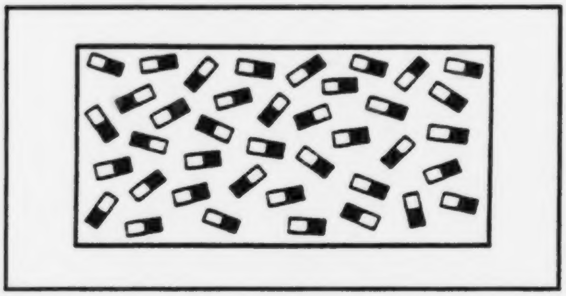


Fig. 6. Unmagnetized iron. (Courtesy of General Motors Corp.)

An outside magnetic force can be used to line up the atom magnets, which will cause the iron bar to become magnetized (fig. 7). The action of each small atom magnet is added to the other small atom magnets to cause the iron bar to have a strong magnetic force.

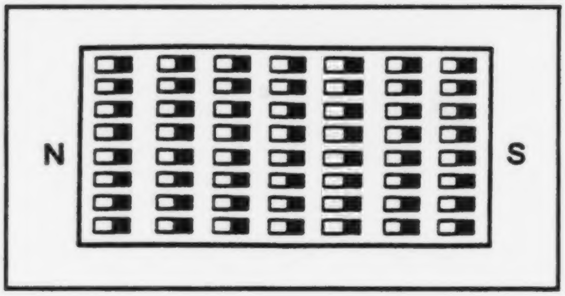


Fig. 7. Magnetized iron. (Courtesy of General Motors Corp.)

Once hard metal alloys become magnetized, their individual atom magnets do not easily change their direction. This type of magnet is called a *permanent magnet*. Soft iron will not hold its magnetism and is suitable for magnets that must be turned on and off, such as a magnet that is made with electricity.

When electric current flows through a wire, it creates a magnetic field (fig. 8). Notice that the lines of force circle the wire and are at a right angle to the flow of current. The magnetic force created by the current in the wire can be concentrated by winding the wire (fig. 9). The magnetic force becomes strongest inside the coil and at the ends of the coil.

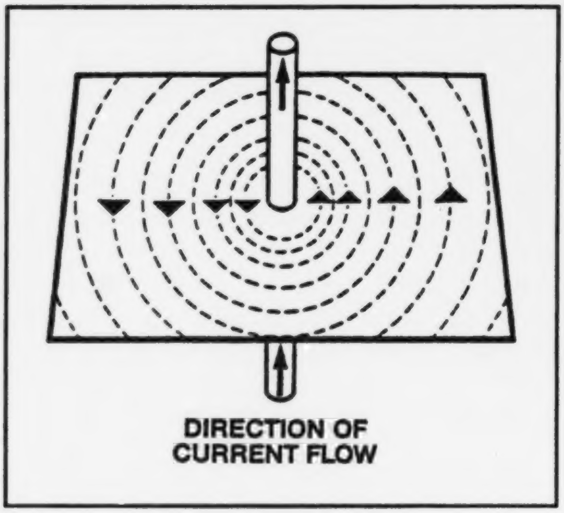


Fig. 8. Current and magnetism. (Courtesy of General Motors Corp.)

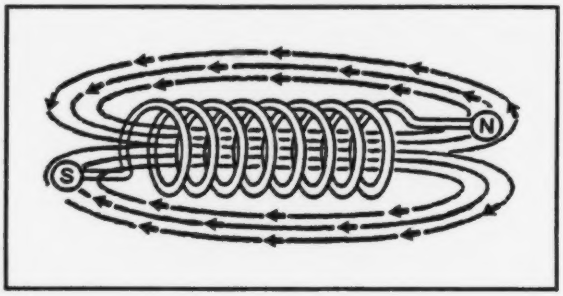


Fig. 9. Coil of wire with air core. (Courtesy of General Motors Corp.)

The strength of the magnetic force, created by the coil, can be changed by changing the amount of current in the wire or the number of turns of wire. Adding an iron core inside the coil of wire will concentrate the lines of force, resulting in a stronger magnetic force at the ends of the coil (fig. 10).

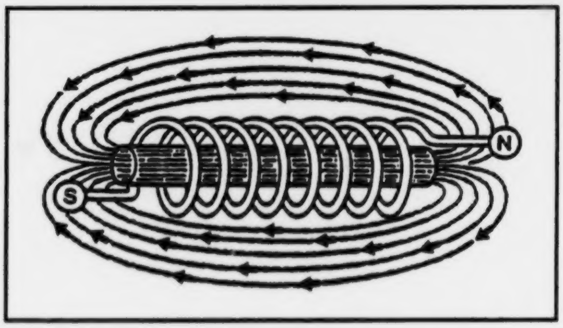


Fig. 10. Coil of wire with iron core. (Courtesy of General Motors Corp.)

Self-Test 1

1. If two bar magnets are allowed to attract each other so that they come together side by side, what will the polarity of the magnets be at each end? The same poles or different poles?
2. Is the north pole of the earth the same polarity as the north pole of a magnet?

Electric Motor Basics

The electric motor uses electricity to make a magnetic field that reacts with another magnetic field in the motor, causing it to run. If a wire that is conducting current is placed in a magnetic field, as shown in figure 11, the wire will be pushed downward. This action of pushing the wire can be increased by looping the wire. The action of a wire that is conducting current and looped in a magnetic field is the basis for an electric motor.

Figure 12 shows an electric motor with the electric current passing through the windings around the magnets, as well as passing through the coil that turns between the magnets.

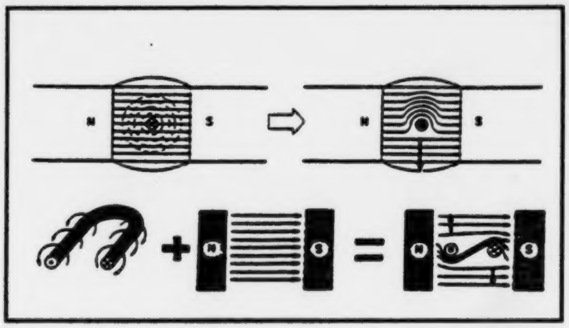


Fig. 11. Interaction of magnetic fields causes motion. (Courtesy of Toyota)

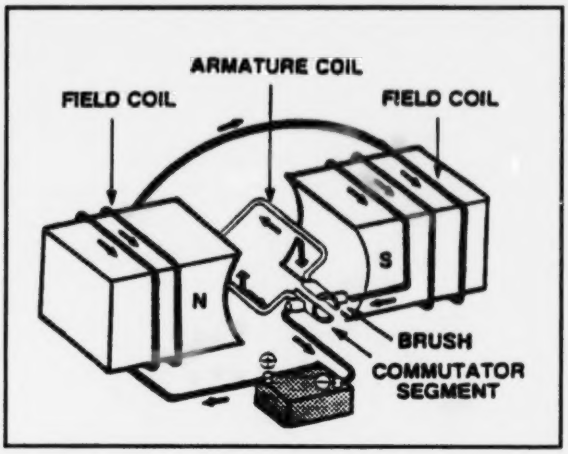


Fig. 12. Current through electric motor. (Courtesy of Toyota)

The coil that turns is called the *armature coil*. The windings that make the magnetic force are called *field coils*. The armature coil will be mounted on a shaft to hold it in the center of the magnetic field. The armature coil is connected to slip rings or the commutator. These make contact with pieces of carbon called *brushes*. The slip rings turn with the armature, and the carbon brushes are stationary. Notice that the current path is through the brushes, commutator, and back to the source. In an actual motor, there are many windings in both the armature coil and field windings.

Many different types of motors are used in the automobile. The motor for the windshield wipers usually has permanent magnets instead of field coils. The motors with field coils can be wired in many different ways (fig. 13).

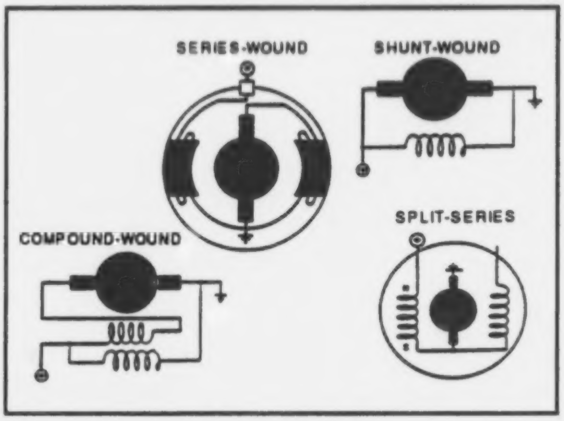


Fig. 13. Series wound, shunt wound, compound wound, and split series wound electric motors. (Courtesy of Toyota)

The series-wound motor has the armature and field coils wired in series. This motor has high torque and will increase in speed when the load on it is reduced. The shunt-wound motor has the armature and field coils wired in parallel. This motor will run at a constant speed, even with changes in the load. The compound-wound motor is a combination of series and parallel. It will operate at a constant speed with high torque. The speed of this motor is easy to change by using resistors in the external control circuitry. The split-series motor can be reversed.

Self-Test 2

1. What arrangement of field coils does the typical windshield wiper motor have?
2. If magnetism causes the electric motor to run, why can't a motor be made that runs on just permanent magnets with no electricity?

Solenoids

A solenoid is an electromagnet. If the iron core in a coil is loose and partly out of the coil when the coil is energized, the magnetic force will pull the core into the coil. This is the basic operation of a solenoid. An electromagnet is a magnet made from a soft iron core with a coil to generate the magnetism.

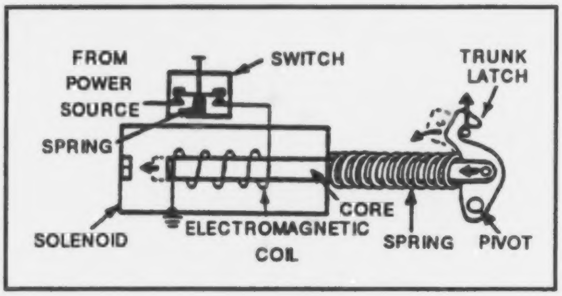


Fig. 14. A solenoid. (Courtesy Ford Motor Company)

Figure 14 shows a solenoid used to release the trunk when a button is pushed on the dash. The spring holds the core out until the switch is pressed down, completing the circuit. When current flows in the coil, it generates a magnetic force that pulls the core in against the spring. This mechanical action releases the trunk latch. When the switch is released, the spring will pull the core back out, causing it to reset.

Relays

A relay is designed to control larger amounts of current with a small amount of current. The relay is an electrical switch. An electromagnet inside the relay will pull and release the switch when it is energized. Relays are specified using the same terminology as switches.

The three different switches in figure 15 illustrate the common variations of switches and relays. If there is only one connection and the switch is either connected to it or nothing, it is a single-pole switch. If the switch is either on or off, it is a single-throw. The single-pole, double-throw shows two possible connections, and the double-pole, single-throw switch shows two switches in one package.

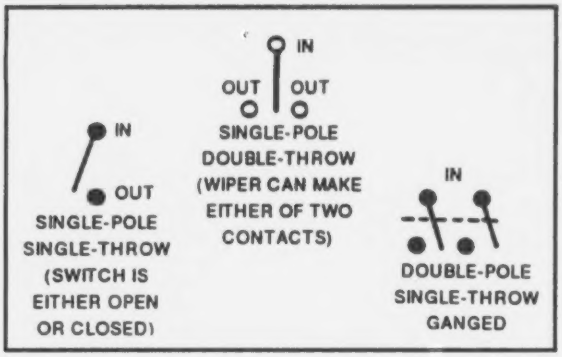

IN
OUT
SINGLE-POLE
SINGLE-THROW
(SWITCH IS
EITHER OPEN
OR CLOSED)
IN
OUT
OUT
SINGLE-POLE
DOUBLE-THROW
(WIPER CAN MAKE
EITHER OF TWO
CONTACTS)
IN
DOUBLE-POLE
SINGLE-THROW
GANGED

Fig. 15. Single-pole, single-throw; single-pole, double-throw; and double-pole, single-throw switches. (Courtesy of Ford Motor Company)

A relay is simply an electric switch and will have all of the single or multiple pole variations. Since a relay can normally have only one of two states, either on or off, the multiple position switch is not used as a relay. When the relay is not energized, the contacts that are not connected are called normally open (NO), and the contacts that are making contact are called normally closed (NC).

The two relays shown in figure 16 illustrate the normally open and normally closed condition. Notice the schematic symbol for the relays. The two relays shown in figure 16 are designed to pull the armature toward the coil when it is energized. The most common applications for relays are the starter motor, fuel pump, and horn relay. Some manufacturers use relays to operate the headlights and fan motors and to energize the air conditioner compressor.

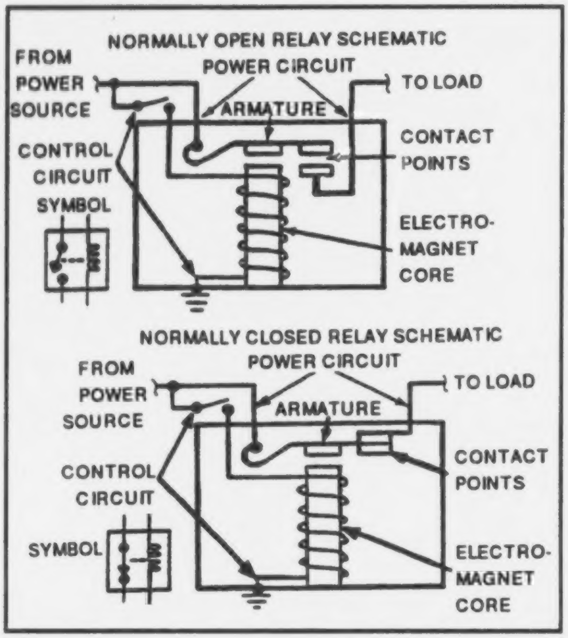

NORMALLY OPEN RELAY SCHEMATIC
FROM POWER SOURCE
POWER CIRCUIT
TO LOAD
ARMATURE
CONTACT POINTS
CONTROL CIRCUIT
SYMBOL
ELECTRO-MAGNET CORE
NORMALLY CLOSED RELAY SCHEMATIC
FROM POWER SOURCE
POWER CIRCUIT
TO LOAD
ARMATURE
CONTACT POINTS
CONTROL CIRCUIT
SYMBOL
ELECTRO-MAGNET CORE

Fig. 16. Relays

A relay will wear out after a certain number of uses. The contacts will become coated and burn away. If you suspect the problem is a relay, disconnect the power from the switch part of the relay, and use the resistance function on your DVOM to measure the resistance through the contacts. There should not be any measurable resistance. Although sometimes the contacts can be cleaned up, it is better to replace a relay when it starts giving problems.

Other Switches

The relay is an electrically operated switch. Two other types are the mercury switch, which is operated by the physical position of the switch, and the bimetallic element switch, which operates based on temperature.

Mercury is a liquid metal that conducts electricity. The switch is made by enclosing some mercury in a container with two terminals (fig. 17). When the container is in the correct position, the mercury will make contact with both terminals and complete the circuit.

A mercury switch is often mounted on the trunk lid to turn on a light when the lid is opened.

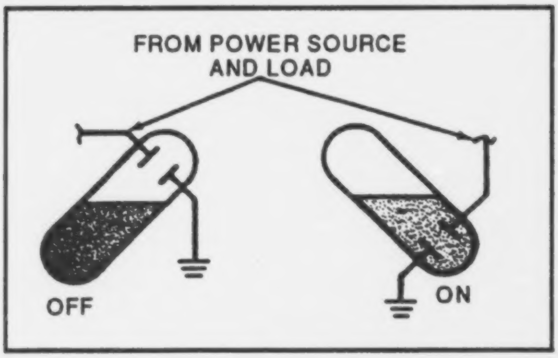

FROM POWER SOURCE AND LOAD
OFF
ON

Fig. 17. Mercury switch. (Courtesy of Ford Motor Company)

A bimetallic element will bend with changes in temperature. The bimetal piece is made by putting two different metals together. The two metals must have different rates of expansion with changes in temperature. As the temperature changes, one of the metal pieces will expand more than the other, causing the assembly to bend. In figure 18, the temperature-sensitive switch is designed to turn on a warning light when the engine temperature becomes too hot. The heat from the engine will cause the element to straighten out and bend toward the contact, completing the circuit and turning on the light on the dash.

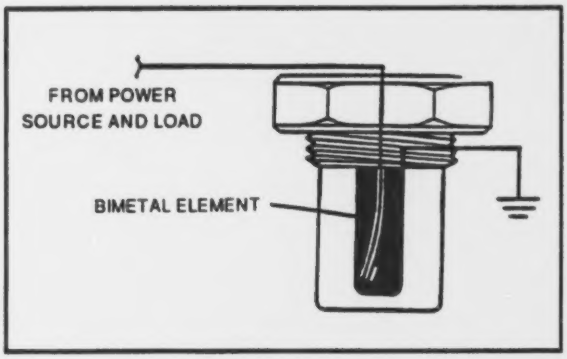

FROM POWER SOURCE AND LOAD
BIMETAL ELEMENT

Fig. 18. Temperature-sensitive switch. (Courtesy of Ford Motor Company)

Figure 19 shows some variation in the use of bimetallic switches. The temperature-sensitive, time-delay switch shown on top has a heating element under the bimetallic strip. When power is first applied, the heating element warms up.

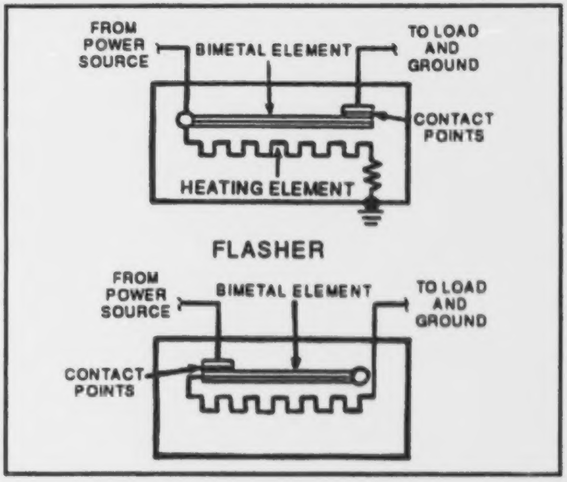

FROM POWER SOURCE
BIMETAL ELEMENT
TO LOAD AND GROUND
CONTACT POINTS
HEATING ELEMENT
FLASHER
FROM POWER SOURCE
BIMETAL ELEMENT
TO LOAD AND GROUND
CONTACT POINTS

Fig. 19. Temperature-sensitive, time-delay switch. (Courtesy of Ford Motor Company)

Current will pass through the switch until the heating element warms the bimetallic strip, causing it to bend enough to break contact with the terminal. As long as current is still applied to the switch, the heating element will hold the switch off and not allow any more current to the load.

This type of switch is often used to control the current to the rear window defroster.

The flasher switch has the heating element wired in series with the switch. When the heating element warms up the bimetallic strip, the whole circuit opens up, and the heating element cools down. This results in the bimetallic strip cooling and returning to make contact, which starts the cycle all over again. This switch has been used for the four-way emergency flashers. Transistor circuits are now starting to replace most switches of this type.

Self-Test 1 Answers

1. *The two magnets will have different poles at each end.*

2. *No! Unlike poles attract. The north pole of a bar magnet is the "north-seeking pole."*

Self-Test 2 Answers

1. *A typical windshield wiper motor uses permanent magnets, so it doesn't have any field coils. The field coils are used to generate magnetism.*

2. *The magnetism has to change based on the position of the armature. Mechanical energy would have to be used to continually change the position of the permanent magnets to make the motor run, which would be self-defeating. A motor cannot be made to run without some energy input.*

Summary

A magnet will attract other magnetic materials such as iron. If the north pole of one magnet is brought close to the north pole of another magnet, the two magnets will repel each other. When the poles are different and they are brought together, they will attract each other.

A wire carrying current has a magnetic field around it. This magnetic field can be made to oppose another fixed magnetic field in a motor causing mechanical action—the motor runs. The moving part of a motor is called the armature coil, and the field coils generate the fixed magnetic force that the armature pushes against.

A solenoid is an electromagnet with a movable core that is pulled when the solenoid is energized. Solenoids are used to release latches on trunk lids and lock or unlock the car doors.

The relay is an electrical switch. A coil generates a magnetic force that closes or opens the switch. Relays are used to control the horn, starter motor, and fuel pump.

Exercise

1. If the number of turns of wire wrapped around an electromagnet is doubled, how will it affect the magnetic force?

2. If the north pole of an electromagnet is brought close to an iron rod so that, when the electromagnet is energized, the iron rod jumps away, what does that indicate about the iron rod?

3. Of what material are the brushes in an electric motor made?

4. What is the part of the electric motor that rotates called?

5. What is the device called that pulls a lever causing the doors to lock electronically?

6. What kind of switch is used to sense an overheated engine?

7. The temperature-sensitive, time-delay switch is wired in series with the ignition switch. The switch is designed to open up after passing current to the rear defrosters for a period of time. If a person left the rear defroster switch on all the time, how many periods of current would the rear window receive during the time this person left home, went to the store, and returned directly back home?

8. The flasher switch has the heating element in series with the current going to the load. If the load is four light bulbs around the car and two light bulbs burn out, how does this affect the rate of heating or the length of each warm-up cycle of the flasher?

C-4 Magnetism

Laboratory Experiment

Essential Elements: (gg) (1-3)

Objective

In this lab, the students will examine the properties of electromagnets.

Equipment

1 voltage source (batteries and battery holder)
3 nails about 2 inches long
4 feet of insulated wire
1 DVOM

Procedure

A solenoid consists of a coil of wire and a plunger or core that can move inside the coil. You will start by making a solenoid.

1. Strip about 1/2 inch of insulation from both ends of a strip of wire 2 feet long. Loosely wrap this wire around one of the nails to form an electromagnet.

2. Test the electromagnet by connecting the wire to the voltage source and try to pick up one of the other nails with the electromagnet. There should be a strong magnet force attracting the other nails.

3. Disconnect one of the wires from the voltage source, and pull the nail about halfway out of the coil. When the wire is reconnected, the nail should pull back into the coil. This is the action of a solenoid. Pull on the nail while current is applied to the coil, and check the strength of your solenoid.

4. Use the other 2 feet of wire to make another electromagnet just like this one.

5. Connect the two electromagnets in parallel, and bring their ends together. Then switch the end of the one of the electromagnets. Why do the magnets attract each other one way and repel each other when their ends are switched?

Note: Do not leave the electromagnets hooked up longer than necessary as they will quickly drain the batteries. In step 5, the electromagnets attract each other when the polarity of the ends that are brought together is different and repel each other when the polarity is the same.

C-5

Schematics (Electrical Road Maps)

Essential Elements: (gg)(1-3)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

Specific Objectives:

After completing this assignment, you will be able to:

- *read and understand automotive electrical drawings*
- *explain the use of good troubleshooting practices*

The Electrical System

The electrical system in an automobile consists of a storage battery and alternator system for the voltage source. The system is controlled by various switches including the ignition switch on the dash. The controls are used to control the various loads such as the lights, starter motor, electric fans, and the engine control systems.

The complete electrical system for an automobile can be shown as symbols on an electrical drawing called a *schematic*. Drawings will vary with different manufacturers, but once you understand one manufacturer's drawings, the others will be easy to comprehend.

The symbol for a ground connection, which is a connection to the chassis of the automobile, is a series of short horizontal lines that get smaller, tapering to a point at the bottom. A wire or component will show on top of the symbol, feeding it (see fig. 1).

The case ground indicates that the component has a metal case, which, when mounted to the chassis, provides a ground connection for the component. The remote ground involves running a wire from the component to a suitable ground.

The fuse is a component that is designed to fail. It is important to remember that the fuse by itself is a reliable component. This means that when a fuse fails, something else in the circuit probably caused it. The schematic symbol for the fuse is shown in figure 2.

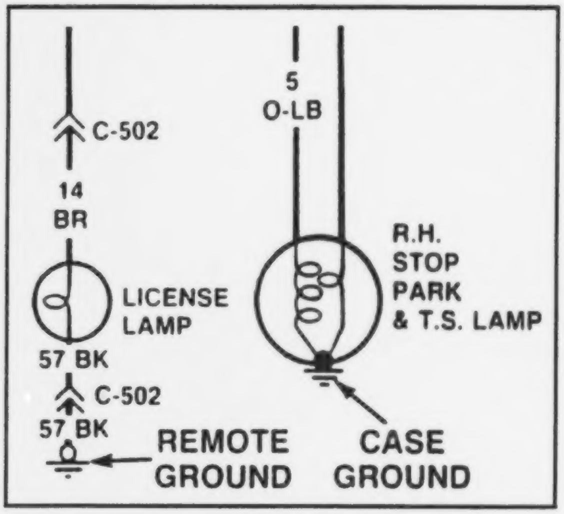


Fig. 1. Case ground and remote ground and their schematic symbols. (Courtesy of Ford Motor Company)

Fuses are made from metal with a low melting point enclosed in either a flat plastic housing or a glass tube. A narrow point is put in the low melting point metal and will melt out when the current exceeds a certain amount. The current rating of a fuse is marked on the body of the fuse, and it may be identified by a color code. Table 1 shows Ford Motor Company's color codes for both fuses and fusible link wire. A fusible link wire is a short length of wire that will be smaller in diameter than the circuit wire it is protecting. The fusible link wire should be four wire gauge sizes smaller.

The circuit breaker shown in figure 3 is designed to interrupt the current flow when the current level gets too high and then reset to protect the circuit again. The circuit breaker may be the type that resets itself, or it may require a manual reset.

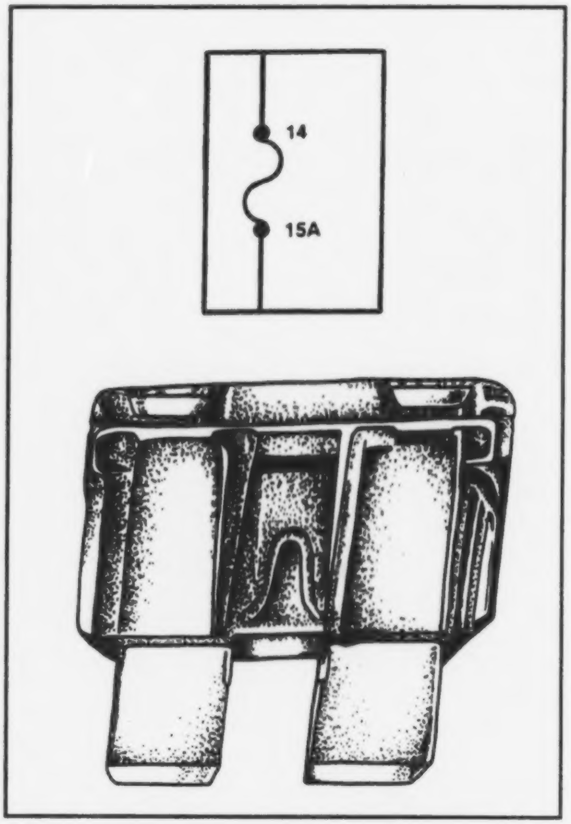


Fig. 2. A typical fuse and its schematic symbol. (Courtesy of Ford Motor Company)

Fuse Value Amp	Color Code	Fuse Link Wire Size	Color Code
4	Pink	20 GA	Blue
5	Tan	18 GA	Brown or Red
10	Red		
15	Lt. Blue	16 GA	Black or Orange
20	Yellow		
25	Natural	14 GA	Green
30	Lt. Green		

Table 1. Fusible Link and Fusible Fuse Code for Ford Motor Company

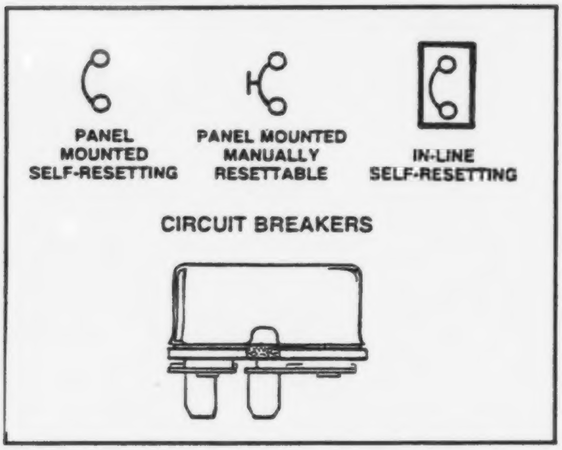

PANEL MOUNTED SELF-RESETTING
PANEL MOUNTED MANUALLY RESETTABLE
IN-LINE SELF-RESETTING
CIRCUIT BREAKERS

Fig. 3. Typical breaker and schematic symbol. (Courtesy of Ford Motor Company)

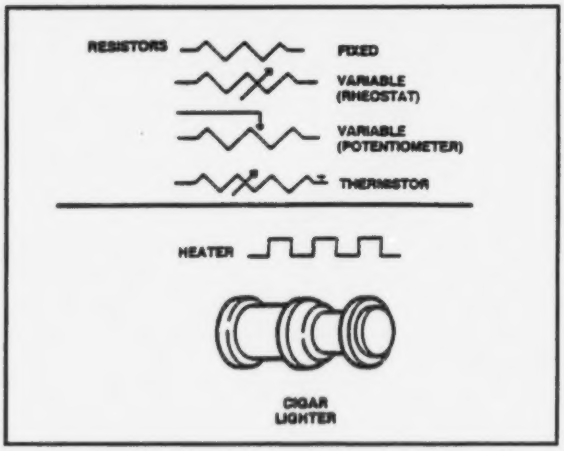

RESISTORS
FIXED
VARIABLE (RHEOSTAT)
VARIABLE (POTENTIOMETER)
THERMISTOR
HEATER
CIGAR LIGHTER

Fig. 4. Various types of resistors. (Courtesy of Ford Motor Company)

Circuit breakers that automatically reset themselves are often made from bimetallic strips. Heat will cause the strip to bend when too much current passes through it, causing the current to be interrupted. When the strip cools down, it will straighten and make contact again, allowing the current to pass on to the load.

Figure 4 shows the symbols for different types of resistors. Notice that the thermistor has a small capital *T* at the end of the symbol. The only difference between the symbol for the rheostat and the one for the thermistor is the letter T at the end of the symbol. Notice that the variable resistors have an arrow to show that they are variable.

A resistance will generate heat and can be considered similar to the heater in the cigar lighter shown in figure 5. This same symbol can be used for the heater in the window defroster and any other electric heater in the automobile.

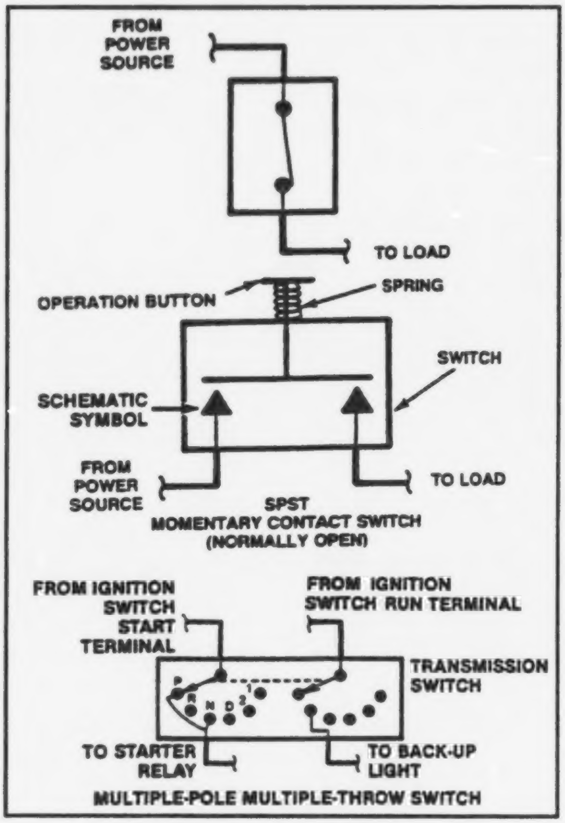

FROM POWER SOURCE
TO LOAD
OPERATION BUTTON
SPRING
SWITCH
SCHEMATIC SYMBOL
FROM POWER SOURCE
TO LOAD
SPST MOMENTARY CONTACT SWITCH (NORMALLY OPEN)
FROM IGNITION SWITCH START TERMINAL
FROM IGNITION SWITCH RUN TERMINAL
TRANSMISSION SWITCH
P
R
N
D
2
1
TO STARTER RELAY
TO BACK-UP LIGHT
MULTIPLE-POLE MULTIPLE-THROW SWITCH

Fig. 5. Types of switches. (Courtesy of Ford Motor Company)

There are many different types of switches in the typical automobile. The single-pole, single-throw switch shown in figure 5 is simply one switch with a single contact. The momentary switch is also a single-pole, single-throw switch. The momentary switch shown in figure 5 has normally open contacts. This means that when the switch is not activated, there is no contact with the terminals. The multiple-pole, multiple-throw switch in figure 5 is two switches ganged together with many contact points.

Troubleshooting

Before you can troubleshoot a problem, you have to understand how the system should work. Next you need to know how to use your test equipment and what results to expect when you conduct a test. Even with this knowledge, you can end up wasting a lot of time if you are not organized. Using a plan for troubleshooting and repairing a problem in a vehicle will save a lot of time and result in higher quality repairs.

The Troubleshooting Plan

The following plan can help you find, repair, and check your work rapidly and accurately. Remember that the quality of the work you do is very important.

1. **Determine the specific complaint.**

   Listen closely when the driver tells you what is wrong, or read the report describing the problem, very carefully. This initial information should tell you under what conditions the problem happens, the duration of the problem, and how long the problem has existed. If possible, ask questions to clarify the problem.

2. **Demonstrate the problem.**

   If the driver says the headlights don't work, try operating the headlights and confirm the problem for yourself. If the car is hard to start, try starting it. Look for clues while running this test. For example, are both headlights completely out or just very dim?

3. **Stop and think!**

   Think about all of the things that you know about the problem and the car. Look at the schematic drawings for the car, and consider what all of the input you have received so far means.

4. **Plan additional tests.**

   Based on the information you presently have and the schematics of the car's electrical system, determine what additional tests are needed to isolate or confirm what and where the problem is. For example, if the headlights do not work, you will need to take voltage measurements at different points to determine where the problem is.

   When deciding where to take your voltage measurements, the best method is to try to split in half the area that needs to be searched. With dead headlights, the problem could be anywhere from the fuse block through the light switch to the wires leading to the headlights. The headlights may have burned out, although it is unusual for both headlights to burn out at the same time unless something else causes them to go. Splitting the area to be searched in half would have you test for voltage in the area of the switch. Testing just past the switch will confirm that the switch is good if there is voltage there. If there is no voltage, check the voltage going into the switch. *Note:* you should know that the fuse is good based on your knowledge of the car. Most fused systems will have more than one function on the fuse. In step 2, you should have checked the other function on that fuse to confirm that it was not the fuse.

When planning your tests, split the area to be checked in half each time you make a test. This rule has to be used based on good judgment concerning the ease of making the tests. If there are points where tests can be made easily and quickly, but these points are not splitting the area in half, good judgment would require that you do these easy tests first.

5. **Locate the problem.**

   Using the tests, you should be able to locate and confirm the problem. Before you correct the problem, make all of the appropriate tests to positively confirm the specific component or part that is at fault. It is generally cheaper and quicker to run a couple more tests than to change a part and find the problem still exists. It is also cheaper to determine that the problem is a loose connection instead of replacing the whole component.

6. **Make the repair.**

   When making the repair, tighten all nuts to the correct torque, use the appropriate gaskets with the correct sealer, and generally do a quality job.

7. **Test the repaired vehicle.**

   For example, if you repaired a burnt wire that had caused the headlights to fail, it is possible that something else caused the wire to burn and will burn it again when you test the repaired system. Give the automobile a thorough test before releasing it back to the driver.

Schematic Diagrams

The schematic in figure 6 shows the power distribution for the tailgate power window of a Ford stationwagon. Notice the two fuse blocks at the top of the drawing.

Figure 7 shows the power distribution for the tailgate power window of a General Motors stationwagon. Although the two drawings appear to have major differences, a closer look will show that the two systems are almost identical.

Notice that both systems have fuse panels or fuse blocks (same thing) feeding power to the window circuitry. One fuse panel or block is on only when the ignition key is on and the other supplies power at all times. There is an interlock switch in line with the power that will bring the window up. This interlock switch will open when the tailgate is open so the window cannot be opened and damaged when the tailgate is open.

Examine figures 6 and 7 carefully, and then answer the self-test questions. The answers to the self-test questions will be in the text that follows the self-test.

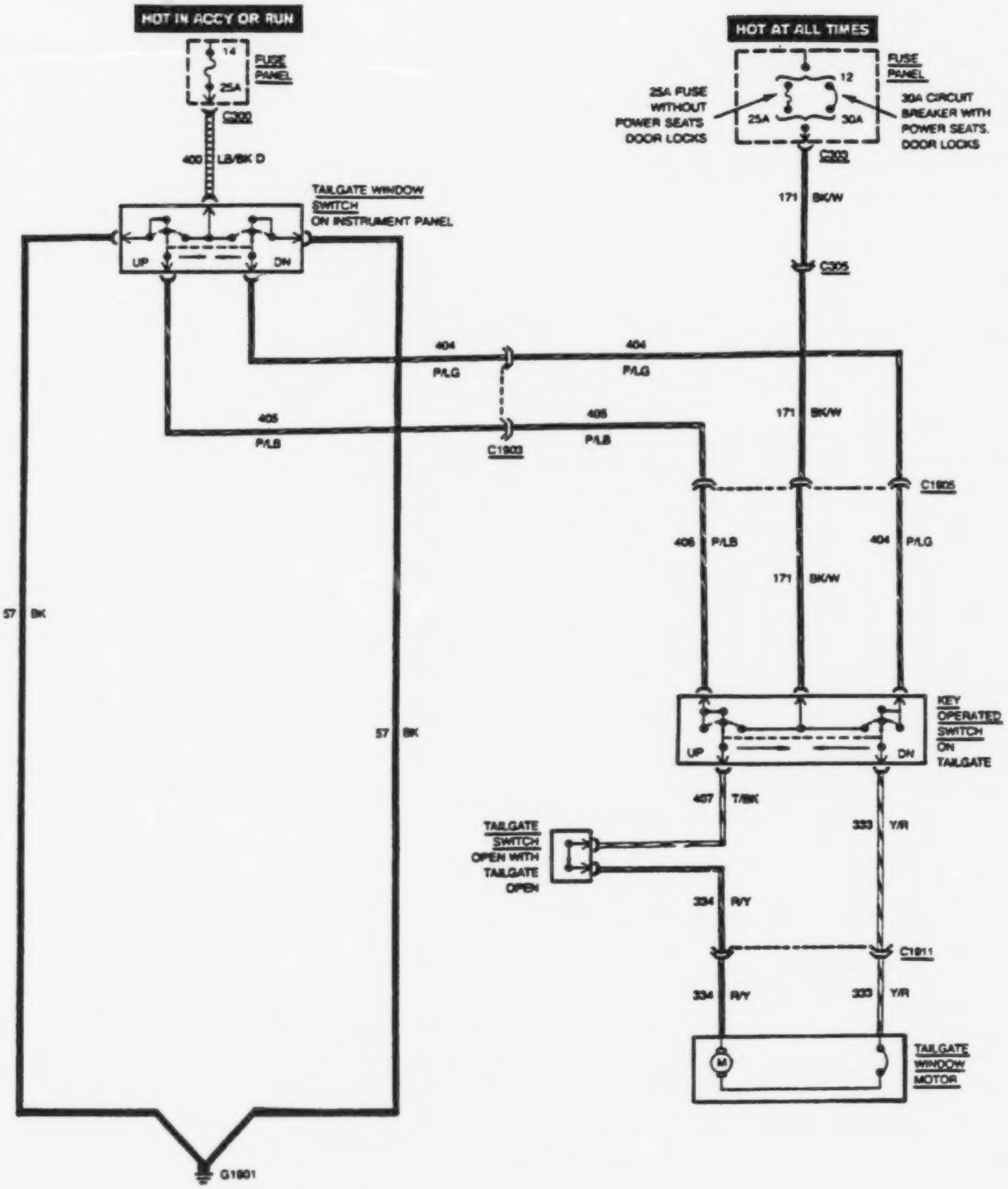

HOT IN ACCY OR RUN
14
25A
FUSE PANEL
C200
400
LB/BK D
TAILGATE WINDOW SWITCH ON INSTRUMENT PANEL
UP
DN
HOT AT ALL TIMES
FUSE PANEL
12
25A FUSE WITHOUT POWER SEATS DOOR LOCKS
25A
30A
30A CIRCUIT BREAKER WITH POWER SEATS, DOOR LOCKS
C200
171
BK/W
C305
404
P/LG
404
P/LG
405
P/LB
405
P/LB
C1903
171
BK/W
C1905
405
P/LB
404
P/LG
171
BK/W
57
BK
57
BK
KEY OPERATED SWITCH ON TAILGATE
UP
DN
407
T/BK
333
Y/R
TAILGATE SWITCH OPEN WITH TAILGATE OPEN
334
R/Y
C1911
334
R/Y
333
Y/R
M
TAILGATE WINDOW MOTOR
G1901

Fig. 6. Ford stationwagon tailgate power window circuit schematic. (Courtesy of Ford Motor Company)

Self-Test

1. A customer comes in with a GM stationwagon and tells you that both the power door locks and the keylock switch for the tailgate window have failed. Looking at the schematic, what is the most likely cause of the problem?
2. Another customer, driving a Ford stationwagon, comes into your shop and tells you that she can no longer raise the tailgate window. She had no problem lowering it, but now she cannot raise it with either the dashboard switch or the tailgate switch. What is the most likely source of the problem?
3. Another customer with a GM stationwagon comes in and tells you that he is having trouble with the tailgate window. It will move either up or down for a moment and then stop. After a short period of time, he can move the window a little further before it stops again. What is the most likely reason for this problem?
4. Another customer, driving a Ford stationwagon, comes into your shop and tells you that she cannot lower the tailgate window from the dash. The key switch on the tailgate works fine, and the switch on the dash will raise the tailgate. Where would you start testing to find the problem?

Troubleshooting the Tailgate Window Circuit

The self-test questions above start you at step three of the troubleshooting plan. In question 1, you are told that you have lost both the power door locks and the keylock switch for the tailgate window. Notice in figure 8 that circuit number 2 with an orange wire and black strip is feeding the power door locks just after the fuse block that is hot all the time. *This circuit has a circuit breaker in the fuse block, which would be the most likely component to check first.*

In question 2, you are told that the tailgate window cannot be raised. *Of course, the problem can be a bad connection or a broken wire, but, the most likely part to check first would be a component like the tailgate blockout switch.* If the wires are installed properly and then tightened properly, there is no reason for them to fail by themselves. A switch can fail through use or abuse more readily than a wire or connection.

Notice that the tailgate blockout switch will keep the window from going up when the tailgate is open. The switch could fail and stay open all the time.

Question 3 takes a little more thought. As you look at the schematic, notice that the motor has a self-resetting circuit breaker. *If the circuit breaker opened as a result of higher current than normal or the circuit breaker was at fault, then when the heater inside the circuit breaker cooled down, the circuit breaker would cycle on again. If this is the problem, then the next step is to determine if the circuit breaker is good and there is too much current flow or the breaker is bad. The publications available to the technician at the dealership will tell you what the current level should be. Use a small resistor in line with the motor, and measure the voltage drop across it. Use Ohm's law to find the current through the motor.*

If the current through the motor is excessive, it could be caused by the motor having to work harder than it should or possibly the windings in the motor are failing. You should avoid replacing the motor until you know that the motor is, in fact, bad.

The problem posed by question 4 will require more testing than the other questions. The problem is that the customer cannot lower the tailgate from the dash and everything else works fine.

When you look at the schematic, you can see that line 404, which passes through two plugs, is the obvious place to start looking. You should use your meter to check whichever plug is easier to get to and then work back if it tests good.

The Black Box

Most modern cars have numerous computer circuits for controlling the engine, body electrical, and brakes. Generally, no provision is made for repairing these modules at the local level. We often call these computer modules the "Black Box." This means that we do not consider what is inside the Black Box, only the inputs and outputs.

The outputs from these modules are often the contacts of a relay. The

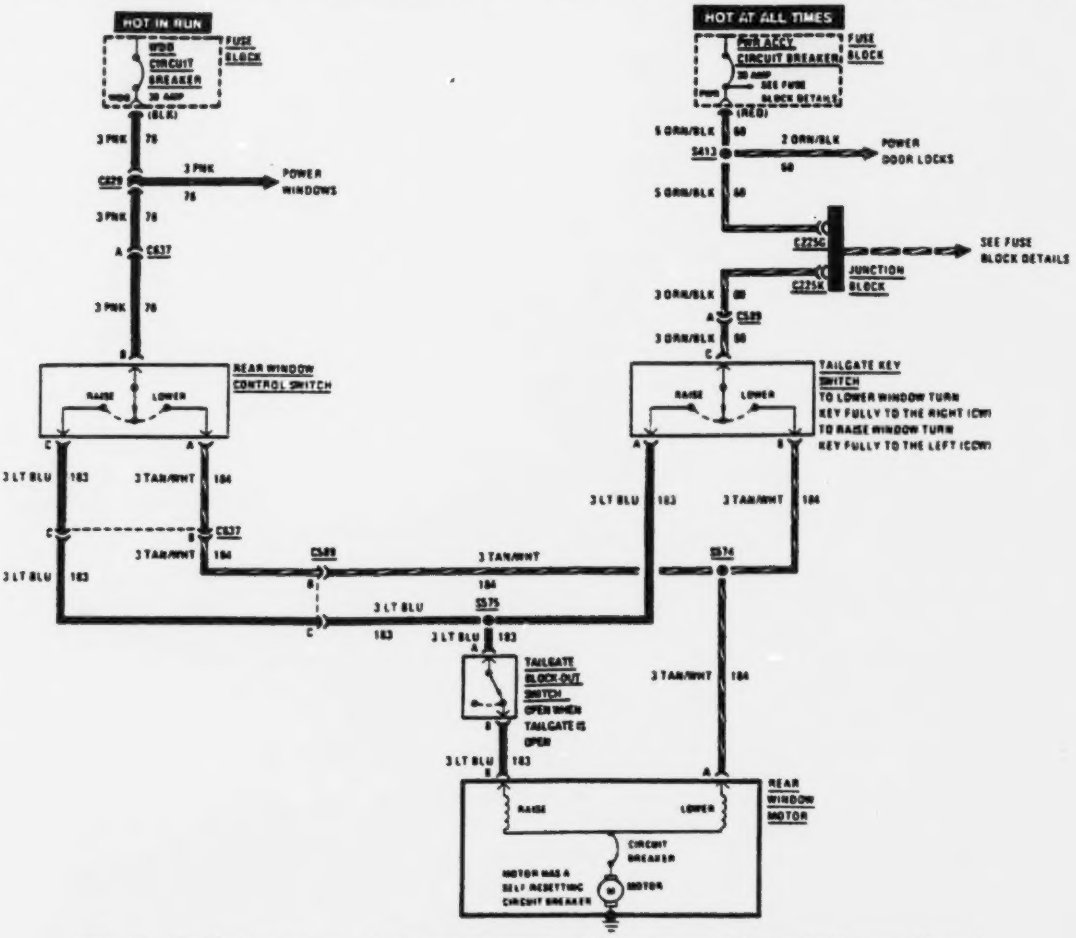

HOT IN RUN
WDO CIRCUIT BREAKER
30 AMP
FUSE BLOCK
(BLK)
3 PNK 76
POWER WINDOWS
C637
REAR WINDOW CONTROL SWITCH
RAISE
LOWER
3 LT BLU 183
3 TAN/WHT 184
S575
S574
TAILGATE BLOCK-OUT SWITCH OPEN WHEN TAILGATE IS OPEN
REAR WINDOW MOTOR
CIRCUIT BREAKER
MOTOR
MOTOR HAS A SELF RESETTING CIRCUIT BREAKER
HOT AT ALL TIMES
CIRCUIT BREAKER
SEE FUSE BLOCK DETAILS
(RED)
5 ORN/BLK 60
2 ORN/BLK
S413
POWER DOOR LOCKS
C225G
C225K
JUNCTION BLOCK
3 ORN/BLK
TAILGATE KEY SWITCH
TO LOWER WINDOW TURN KEY FULLY TO THE RIGHT (CW)
TO RAISE WINDOW TURN KEY FULLY TO THE LEFT (CCW)

Fig. 7. Tailgate power window schematic. (Courtesy of General Motors Corp.)

inputs are usually highly buffered inputs to an integrated circuit. A buffered input is a circuit between the integrated circuit and the circuitry outside of the module that receives the input signal before the integrated circuit. The buffer circuitry will clean up the input signal and keep any voltage surges or other harmful signals from damaging the integrated circuit.

Examine figure 8, and notice that the power for the circuit comes from the fuse panel shown at the top left. Two grounds are shown at the bottom. This schematic shows the wiring details for a group of bulbs on the instrument panel. This circuit shows that all the bulbs are controlled from the one switch labeled *main light switch* just under the fuse panel. There is another fuse panel between the switch and the working lights.

With this information in mind, you can trace the flow of current through any of the bulbs. It is important to have a general understanding of the equipment, as well as being able to look at the schematic, to effectively troubleshoot a problem in equipment.

Different manufacturers draw their schematics in different ways. Notice that this schematic shows the conductors that are supplying the current as striped and the ground conductors as solid black. You can trace the flow of current for this

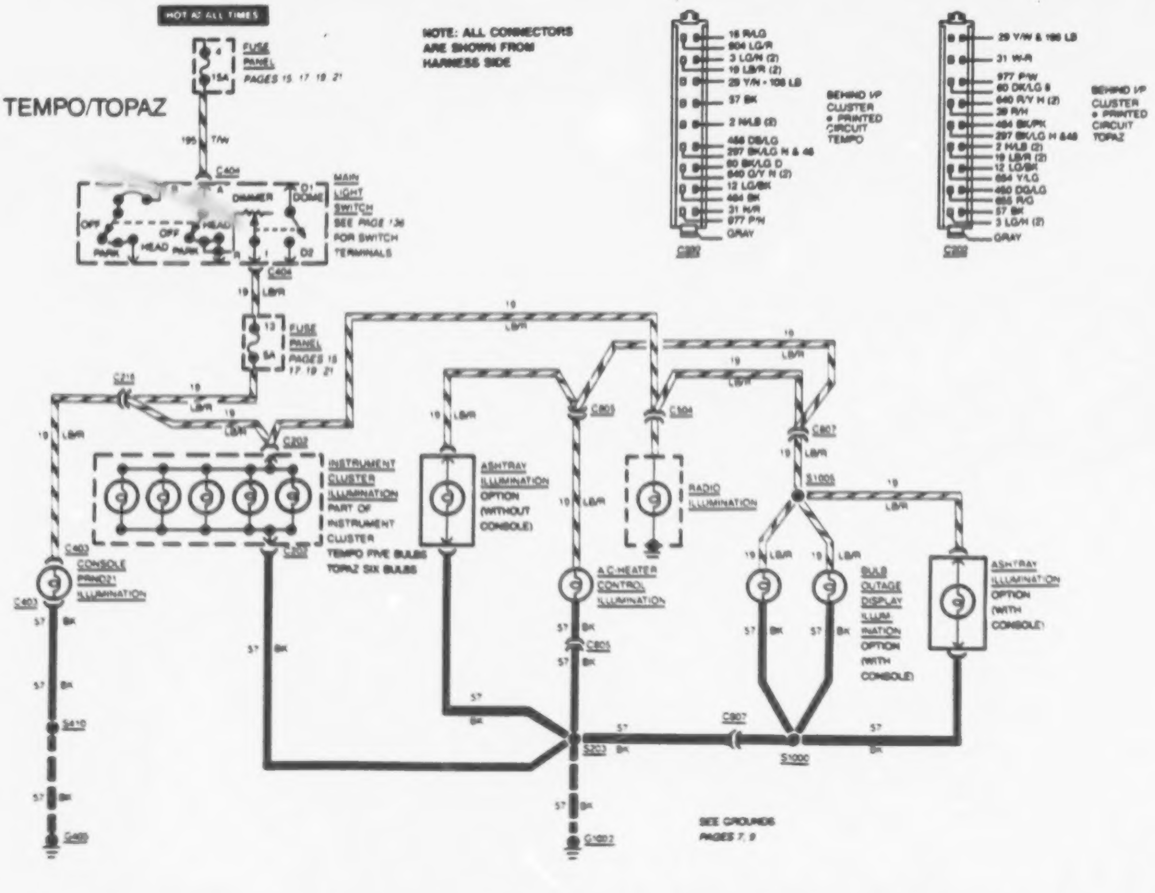

HOT AT ALL TIMES
TEMPO/TOPAZ
NOTE: ALL CONNECTORS ARE SHOWN FROM HARNESS SIDE
FUSE PANEL PAGES 15, 17, 19, 21
15A
195 T/W
C404
MAIN LIGHT SWITCH SEE PAGE 136 FOR SWITCH TERMINALS
DIMMER
DOME
OFF
HEAD
PARK
19 LB/R
FUSE PANEL PAGES 15, 17, 19, 21
5A
C216
C202
INSTRUMENT CLUSTER ILLUMINATION PART OF INSTRUMENT CLUSTER TEMPO FIVE BULBS TOPAZ SIX BULBS
ASHTRAY ILLUMINATION OPTION (WITHOUT CONSOLE)
C805
C504
RADIO ILLUMINATION
C807
S1005
A/C-HEATER CONTROL ILLUMINATION
BULB OUTAGE DISPLAY ILLUMINATION OPTION (WITH CONSOLE)
ASHTRAY ILLUMINATION OPTION (WITH CONSOLE)
C403
CONSOLE PRND21 ILLUMINATION
57 BK
S410
G400
S203
S1000
G1002
SEE GROUNDS PAGES 7, 9
16 R/LG
904 LG/R
3 LG/W (2)
19 LB/R (2)
29 Y/W • 108 LB
57 BK
2 W/LB (2)
486 DB/LG
297 BK/LG H & 46
60 BK/LG D
640 O/Y H (2)
12 LG/BK
484 BK
31 W/R
977 P/W
GRAY
BEHIND I/P CLUSTER • PRINTED CIRCUIT TEMPO
C200
29 Y/W & 198 LB
31 W-R
977 P/W
60 DK/LG 8
640 R/Y H (2)
39 R/H
484 BK/PK
297 BK/LG H 848
2 W/LB (2)
19 LB/R (2)
12 LG/BK
684 Y/LG
460 DG/LG
655 R/G
57 BK
3 LG/W (2)
GRAY
BEHIND I/P CLUSTER • PRINTED CIRCUIT TOPAZ
C200

Fig. 8. Schematic for instrument illumination. (Courtesy of Ford Motor Company)

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schematic as starting at the fuse panel at the top left. The current flows down through the tan wire number 195 and into the main light switch module. There is a notation to see page 136 for more details of the switch module. This notation refers to the master book from which this drawing came.

The current leaves the main light switch at plug C404 and travels down the light brown wire numbered 19. Here the current enters the fuse panel and leaves on the same color and number wire. The junction at C216 splits and allows the current to travel both to the console PRND21 illumination and to the instrument cluster illumination module. A junction at the plug on the instrument cluster illumination sends the current on to the radio illumination and from there to plug C807, which splits into two directions.

The schematic shows you where the cable harness splits, which can make signal tracing easier. The details on the switches and complex components are covered on other pages or in other documents, as shown in the schematic.

Summary

Electrical diagrams show the path that current will take and use a variety of symbols for the different components. The basic resistor is a zigzag line, while the ground connection is a series of horizontal lines that shorten to a dot at the bottom. Most modules and complex components show as a box, with a label explaining what the box is.

An organized plan for troubleshooting will save a lot of time and frustration when you are trying to determine what is causing a particular problem. We have developed a seven-step plan to help make troubleshooting more efficient.

1. Determine the specific complaint.
2. Demonstrate the problem.
3. Stop and think!
4. Plan additional tests.
5. Locate the problem.
6. Make the repair.
7. Test the repaired vehicle.

All complex electrical problems will require that you examine the schematic drawings for that vehicle before you start working on the vehicle. Experience with electrical drawings will improve your expertise at finding and repairing difficult electrical problems.

Exercise

Refer to figure 9 to answer the following questions.

1. What two plugs have to be disconnected to remove the left front door lock switch?

2. What color wire feeds the current to the front door lock motors to unlock the doors?

3. What kind of high current protection does each motor have inside the motor housing?

4. What kind of switch/relay is in the door lock relay assembly? (single-pole, double-throw; double-pole, single-throw; single-pole, single-throw; or double-pole, double-throw)?

5. What part of the circuit will still work, if the 20 amp fuse (CTSY-CLK FUSE) blows?

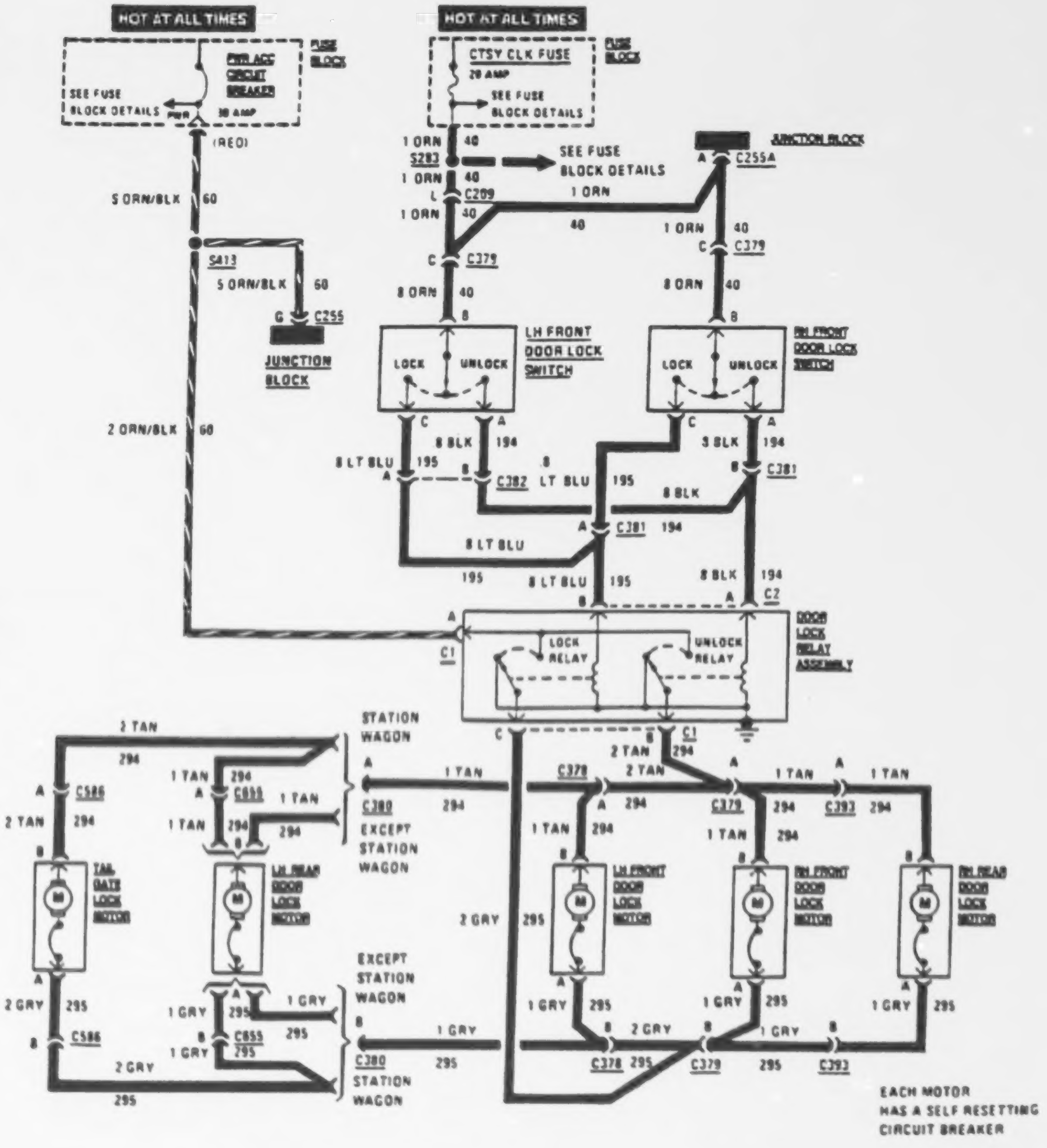
HOT AT ALL TIMES
PWR ACC CIRCUIT BREAKER
30 AMP
SEE FUSE BLOCK DETAILS
FUSE BLOCK
HOT AT ALL TIMES
CTSY CLK FUSE
20 AMP
SEE FUSE BLOCK DETAILS
FUSE BLOCK
(RED)
5 ORN/BLK 60
S413
5 ORN/BLK 60
G C255
JUNCTION BLOCK
2 ORN/BLK 60
1 ORN 40
S283
SEE FUSE BLOCK DETAILS
1 ORN 40
L C209
1 ORN 40
1 ORN 40
JUNCTION BLOCK
A C255A
1 ORN 40
C C379
C C379
8 ORN 40
8 ORN 40
LH FRONT DOOR LOCK SWITCH
RH FRONT DOOR LOCK SWITCH
LOCK
UNLOCK
8 LT BLU 195
8 BLK 194
C382
8 LT BLU 195
8 BLK
3 BLK 194
C381
8 LT BLU
C381 194
8 LT BLU 195
8 BLK 194
C2
DOOR LOCK RELAY ASSEMBLY
LOCK RELAY
UNLOCK RELAY
C1
2 TAN 294
STATION WAGON
1 TAN 294
C586
C655
1 TAN
C380
EXCEPT STATION WAGON
C378
C379
C393
1 TAN 294
2 TAN 294
TAIL GATE LOCK MOTOR
LH REAR DOOR LOCK MOTOR
LH FRONT DOOR LOCK MOTOR
RH FRONT DOOR LOCK MOTOR
RH REAR DOOR LOCK MOTOR
2 GRY 295
1 GRY 295
EXCEPT STATION WAGON
C380
STATION WAGON
C586
C655
C378
C379
C393
EACH MOTOR HAS A SELF RESETTING CIRCUIT BREAKER

Fig. 9. Four-door power door lock circuit schematic. (Courtesy of General Motors Corp.)

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C-5 Schematics (Electrical Road Maps)

Workbook

Essential Elements: (gg) (1-3)

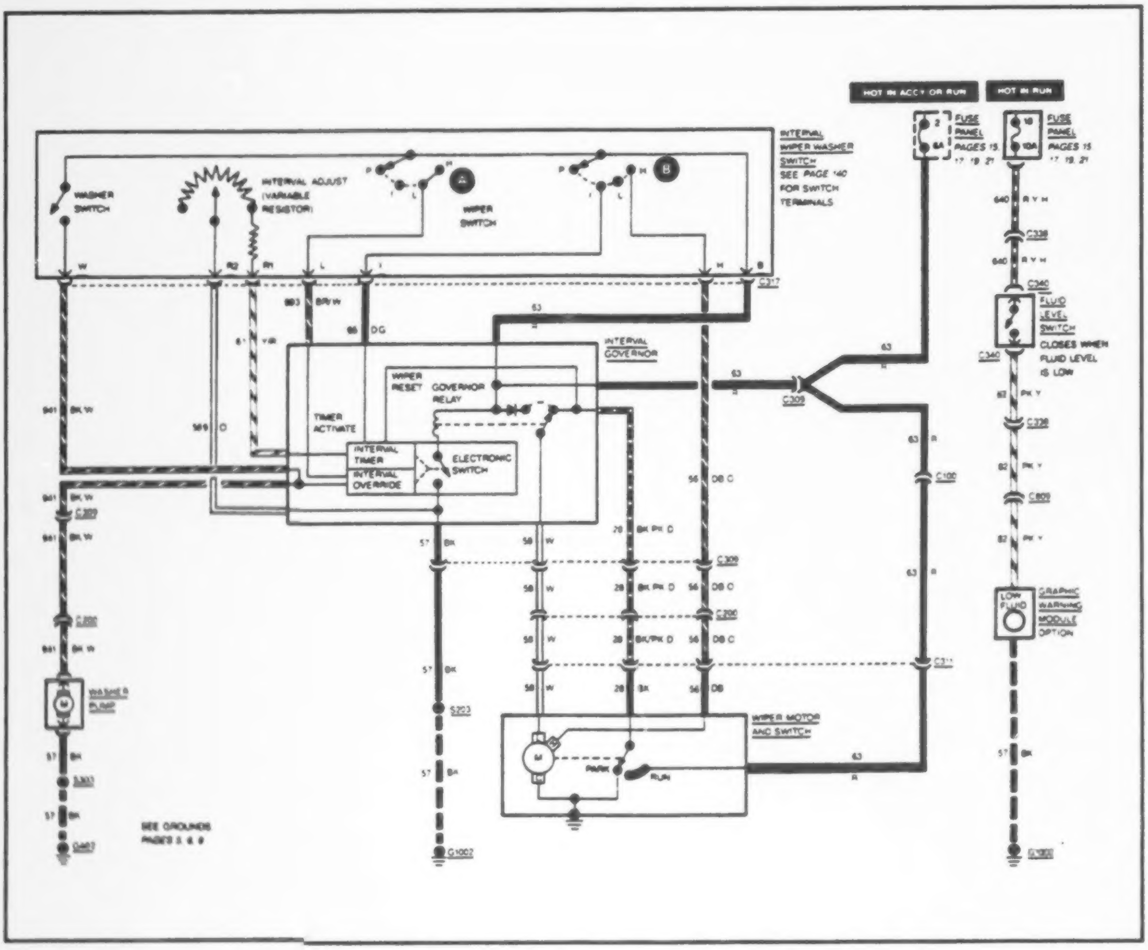

HOT IN ACCY OR RUN
HOT IN RUN
FUSE PANEL PAGES 15 17 19 21
2
6A
10
10A
INTERVAL WIPER WASHER SWITCH
SEE PAGE 140 FOR SWITCH TERMINALS
WASHER SWITCH
INTERVAL ADJUST (VARIABLE RESISTOR)
WIPER SWITCH
P
L
H
A
B
W
R2
R1
C317
INTERVAL GOVERNOR
WIPER RESET
GOVERNOR RELAY
TIMER ACTIVATE
INTERVAL TIMER
INTERVAL OVERRIDE
ELECTRONIC SWITCH
993 BR/W
90 DG
61 Y/R
589 O
941 BK/W
63 R
56 DB O
28 BK PK O
58 W
57 BK
C309
C100
C311
C200
C338
C340
C328
C809
640 R Y H
FLUID LEVEL SWITCH
CLOSES WHEN FLUID LEVEL IS LOW
82 PK Y
LOW FLUID
GRAPHIC WARNING MODULE OPTION
WASHER PUMP
M
S203
G1002
SEE GROUNDS PAGES 3, 6, 9
WIPER MOTOR AND SWITCH
PARK
RUN

Fig. 1. Ford interval windshield wiper/washer schematic

1. For the drawing in figure 1, on a separate sheet of paper, list the items that the current will pass through from the fuse panel (hot in accy or run) to the "L"

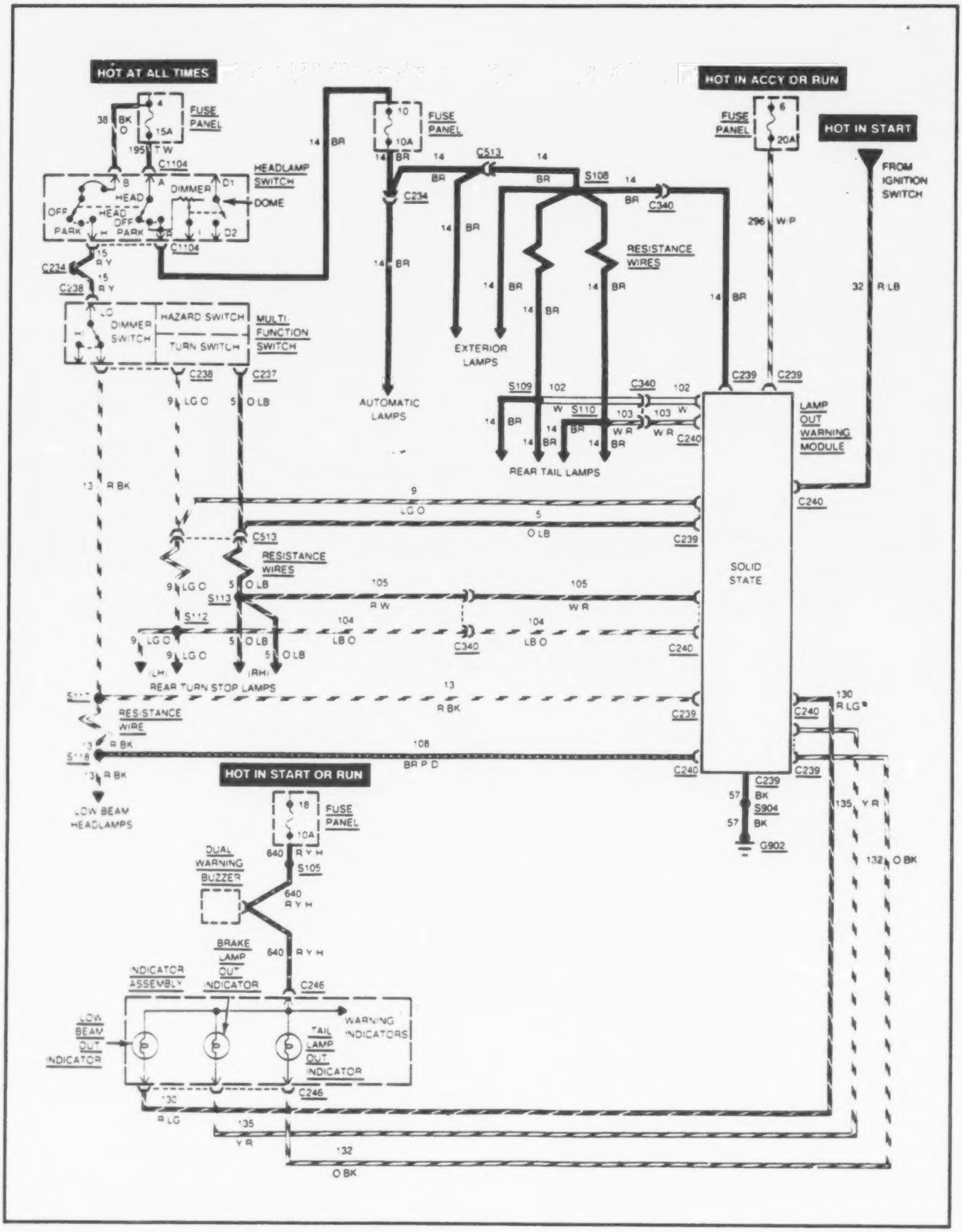

HOT AT ALL TIMES
FUSE PANEL
15A
HEADLAMP SWITCH
OFF
HEAD
PARK
DIMMER
DOME
C1104
C234
C238
HAZARD SWITCH
DIMMER SWITCH
TURN SWITCH
MULTI-FUNCTION SWITCH
C237
FUSE PANEL
10A
C513
S108
C340
RESISTANCE WIRES
AUTOMATIC LAMPS
EXTERIOR LAMPS
S109
S110
REAR TAIL LAMPS
HOT IN ACCY OR RUN
FUSE PANEL
20A
HOT IN START
FROM IGNITION SWITCH
296 W/P
32 R LB
C239
C240
LAMP OUT WARNING MODULE
SOLID STATE
RESISTANCE WIRES
S113
S112
REAR TURN STOP LAMPS
(LH)
(RH)
RESISTANCE WIRE
S117
S118
LOW BEAM HEADLAMPS
108 BR P D
13 R BK
130 R LG
135 Y R
132 O BK
S904
G902
HOT IN START OR RUN
FUSE PANEL
10A
640 R Y H
S105
DUAL WARNING BUZZER
BRAKE LAMP OUT INDICATOR
INDICATOR ASSEMBLY
C246
WARNING INDICATORS
LOW BEAM OUT INDICATOR
TAIL LAMP OUT INDICATOR

Fig. 2. Ford lamp out warning system

input of the wiper motor. Include the number showing the wire or wire harness, each numbered plug, the interval governor, and any numbered junctions or splits.

2. In figure 1, notice the black wire with white strip, #941. If wire #941 coming from point W on the interval wiper/washer switch was shorted to wire #941 in plug C309, describe the effect on the circuit.

   The lamp out warning system shown in figure 10 uses resistance wire for a voltage drop when there is current flow. Notice where the wire shows the zigzag just like a resistor symbol. With all lamps on, the voltage drop will be around 0.5 volt. When a lamp goes out, the voltage drop goes down to 0.25 volt. The solid-state module will see this small difference in voltage and turn on a warning indicator by grounding that circuit.

3. A customer comes in and shows you that one low beam headlight is out and the indicator light is not on. You refer to figure 2 for the circuit and check the indicator by removing a tail light. The indicator does not show the loss of the tail light. What would you recommend to look at next?

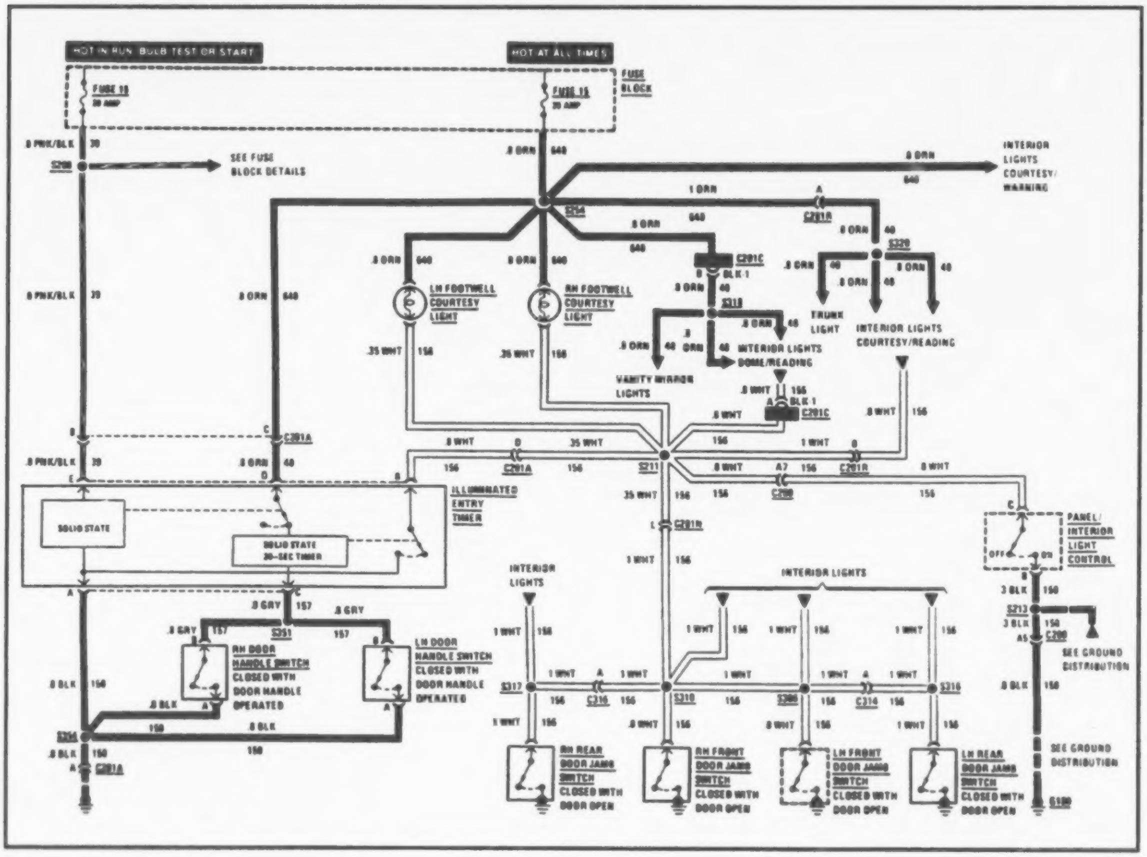

HOT IN RUN, BULB TEST OR START
HOT AT ALL TIMES
FUSE BLOCK
SEE FUSE BLOCK DETAILS
INTERIOR LIGHTS COURTESY/WARNING
LH FOOTWELL COURTESY LIGHT
RH FOOTWELL COURTESY LIGHT
TRUNK LIGHT
INTERIOR LIGHTS COURTESY/READING
INTERIOR LIGHTS DOME/READING
VANITY MIRROR LIGHTS
ILLUMINATED ENTRY TIMER
SOLID STATE
SOLID STATE 30-SEC TIMER
PANEL/INTERIOR LIGHT CONTROL
OFF
ON
INTERIOR LIGHTS
RH DOOR HANDLE SWITCH CLOSED WITH DOOR HANDLE OPERATED
LH DOOR HANDLE SWITCH CLOSED WITH DOOR HANDLE OPERATED
RH REAR DOOR JAMB SWITCH CLOSED WITH DOOR OPEN
RH FRONT DOOR JAMB SWITCH CLOSED WITH DOOR OPEN
LH FRONT DOOR JAMB SWITCH CLOSED WITH DOOR OPEN
LH REAR DOOR JAMB SWITCH CLOSED WITH DOOR OPEN
SEE GROUND DISTRIBUTION
SEE GROUND DISTRIBUTION
C201A
C201C
C201R
S211
S251
S213
S317
S310
S316
C316
C314

Fig. 3. GM illuminated entry

Figure 3 shows the circuit for the illuminated entry. This circuitry will cause the inside lights to go on when the door handle is operated. There is a 20-second timer that will keep the lights on after the door handle is operated.

Examine figure 3, and notice that when the door handle is operated, it will provide the path to ground for the 20-second timer in the illuminated entry timer module. When this ground circuit is made, the relay pulls the contacts closed on terminal B. The relay closure on terminal B provides a ground for the footwell courtesy lights. When the ignition key is ON, current will be supplied through fuse number 16 to the solid-state module. This will open the switch at terminal D and disable the 20-second timer.

4. In figure 3, if a short to ground happened where the white wire connects to the right footwell courtesy light, what would happen to the interior lights?

5. In figure 3, what would happen if fuse number 15 opened?

C-6

AC and Computer Signals

Essential Elements: (gg)(1-3)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how to use an oscilloscope to measure the frequency and voltage level of a signal*
- *explain how a capacitor works in a circuit*
- *explain what an ac signal is and how it is made by the alternator*

AC and Pulse Signals

You have already learned that when a coil of wire is in a magnetic field and has current flowing through it, the magnetic forces will push on the coil. The pushing from the magnetic forces results in the electric motor. This particular action resulting in a motor will also work the other way. If you don't pass any current through the wire and mechanically spin the coil in the magnetic field, the coil will have current induced in it. This will result in an electric generating alternator as shown in figure 1.

In the early automobiles, electric generators were commonly used to recharge the batteries. The generator, like a motor, has slip rings which take the current from the coil or armature to the load. These slip rings are designed to always deliver current in the same direction. The more modern alternator allows the current to flow in both directions, which is more efficient. Diodes, which you will study later, are used to convert this changing direction back to all one direction that can be used in the automobile.

Notice the curved line at the bottom of figure 1. This represents the voltage output from the alternator. As the coil passes through the magnetic lines of force, the amount of voltage generated will vary depending on the position of the coil.

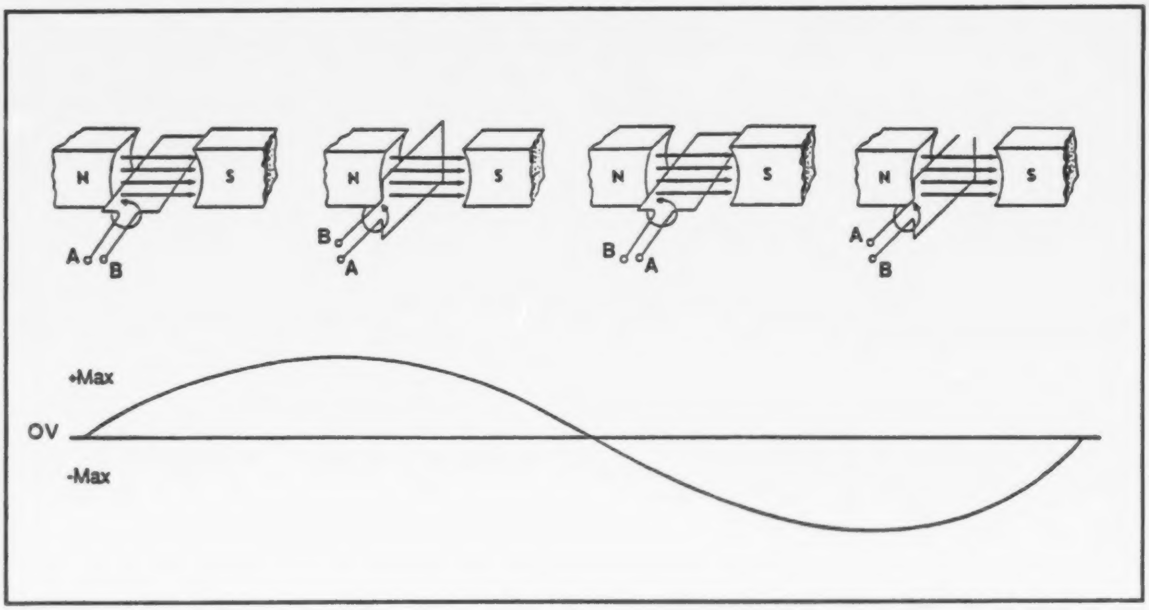


Fig. 1. Graph of voltage

The current also changes direction as a result of the position of the coil in the magnetic field. This changing of voltage and direction is graphed in the curved line below the illustration of the alternator.

The curved line showing the voltage output is called a *sine wave*. The sine is a mathematical ratio, which students normally learn about in trigonometry classes. This sine wave was developed as a result of turning the coil in the magnetic field. One revolution of the coil is 360 degrees and is also one wave (fig. 2).

In figure 2, degrees are shown, as well as the angle in radians. Radians is another way of measuring an angle. The straight horizontal line through the center of the sine wave represents zero volts and can be considered the base line. Going up from the zero volts line is increasing in positive voltage. Going down from the zero volts line is increasing in negative voltage.

The degrees, which are read horizontally, represent the position of the coil in the magnetic field and also represent specific voltage levels. It takes time for the coil to turn one complete revolution in the magnetic field. This time is represented horizontally as well. The amount of time that it takes for one revolution or one complete wave is called the **period**. The number of waves in a second is called the **frequency**. Mathematically, the period and the frequency are related according to the following formula.

$$P = \frac{1}{F} \text{ or } F = \frac{1}{P}$$

The letter *P* stands for the period in seconds, and the letter *F* stands for the frequency.

From	To			
	Effective	Average	Peak	Peak-to-Peak
Effective(rms)		0.900	1.414	2.828
Average	1.110		1.571	3.142
Peak	0.707	0.637		2.000
Peak-to-Peak	0.354	0.318	0.500	

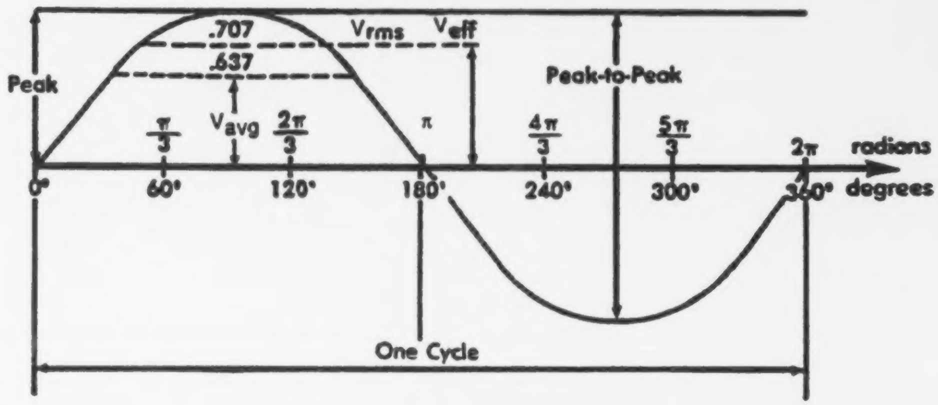


Fig. 2. Sine wave relationships

This sine wave representation of voltage or current is called alternating current or a.c. When you use the abbreviation a.c. from now on, you will drop the periods after the *a* and the *c*. In an ac signal, the voltage is always changing. This continually changing voltage requires us to be more specific when you state that you have a certain ac voltage. For example, 10 volts ac can be confusing if you don't know where on the sine wave you are looking for the 10 volts.

The chart above the sine wave in figure 2 shows the different places that you can look at any sine wave when describing the voltage level of that sine wave. A sine wave that is 10 volts peak will reach a maximum of 10 volts at 90 degrees and will reach a maximum of 10 volts at 270 degrees. This is the maximum voltage either positive or negative that the sine wave ever reaches.

The effective or rms value is equal to 0.707 times the peak voltage. This value is important because it represents the voltage of a sine wave that will do an equal amount of work as that amount of direct current. Direct current is a signal that has a constant voltage such as the voltages that you have already been working with.

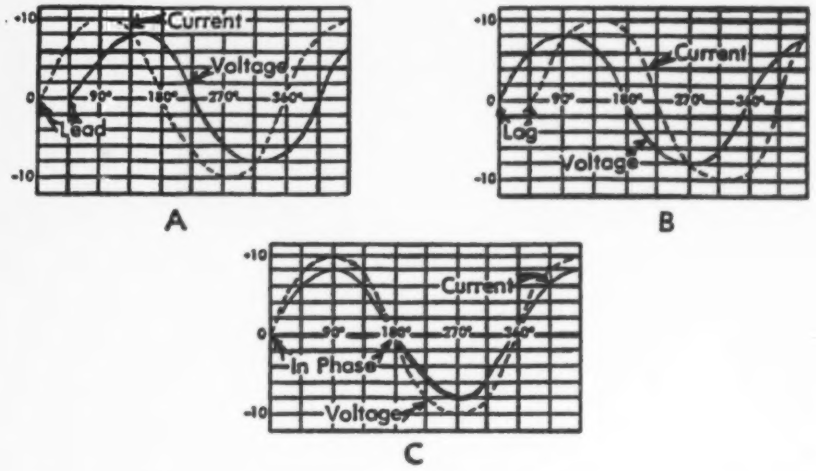


Fig. 3. Alternating current and voltage may either lead or lag each other depending on circuit condition.

When you plug an appliance into the wall for the 115 volts ac, this is 115 volts rms.

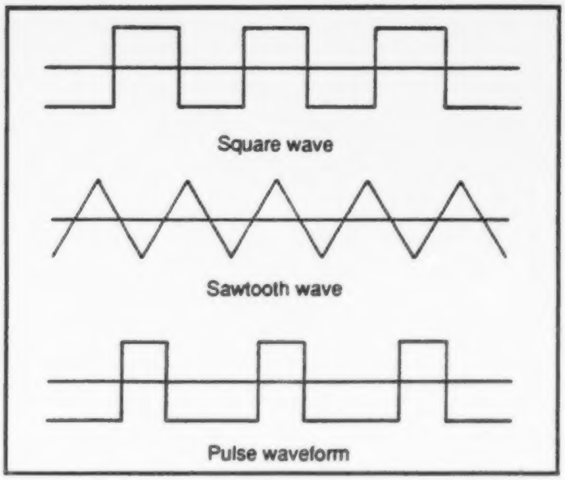
The peak-to-peak voltage is useful when working with an oscilloscope. This *peak-to-peak* is simply the total voltage from the top of the sine wave to the bottom, or twice the peak value of voltage. The average voltage is a mathematical average of the changing voltage in a sine wave.

The voltage and current in an ac signal do not have to reach their peak at the same time. A capacitor in an ac circuit can cause the sine wave for the current to reach a peak at a point that is 90 degrees different from the voltage peak. Also, when two ac signals that have the same frequency are combined, they may not reach their peaks at the same time. You call this difference between signals reaching their peak, the *phase difference*. The phase difference is expressed in degrees.

Figure 3 shows three graphs of a signal voltage compared with its current. In graph A, the voltage leads the current by 45 degrees, and in graph B the voltage lags the current by 45 degrees. Graph C shows the voltage and current in phase with different amplitudes.

The sine wave is a basic wave in nature. Other types of waves are the square wave, sawtooth wave, and pulse waveforms (fig. 4).

These waveforms are called *nonsinusoidal* (not sine wave). The pulse waveform at the bottom of figure 4 is the most common waveform in computer circuits. For most computer circuitry in automobiles, the top of the waveform will be a positive 5 volts or close to that, and the bottom will be 0 volts. The period of the wave is important and is measured from halfway up the transition from 0 to 5 volts at the start of the wave to the same halfway point at the end of the wave. The terms *rms* and *peak value* have little meaning with nonsinusoidal waves.



Square wave

Sawtooth wave

Pulse waveform

Fig. 4. Nonsinusoidal waveforms

Oscilloscope

A typical dual channel oscilloscope is shown in figure 5. The oscilloscope is used to see the waveforms in a circuit. The grid on the face of the screen can be used to take measurements of the signal voltage, phase difference, and frequency.

The term *oscilloscope* is often shortened to just *scope*. There are a number of locations where troubleshooting sensors and computer modules make the scope indispensable. For automotive use, a small scope with a battery pack, to make it completely portable, is recommended.

Figure 6 shows the block diagram of a typical scope. Electrons are fired at the screen from the electron gun. The focusing magnets in the gun direct the stream of electrons to the center of the screen, creating a bright spot, when there is no input.

The input to the scope comes in the probes and into the vertical amplifier, which is a voltage amplifier. If the input is a sine wave, then the bright spot will go up and down the screen with the changes in voltage from the input. The sweep generator and horizontal amplifier create a voltage that moves the stream of electrons from the left side of the screen to the right side. The stream of electrons or the spot is then blanked out for the return to the left side, and the process starts over. If the scope is adjusted so that the time taken for one sweep across the face of the screen by the sweep generator and horizontal amplifier is equal to the period of the sine wave coming in the input, then one sine wave will be displayed on the screen.

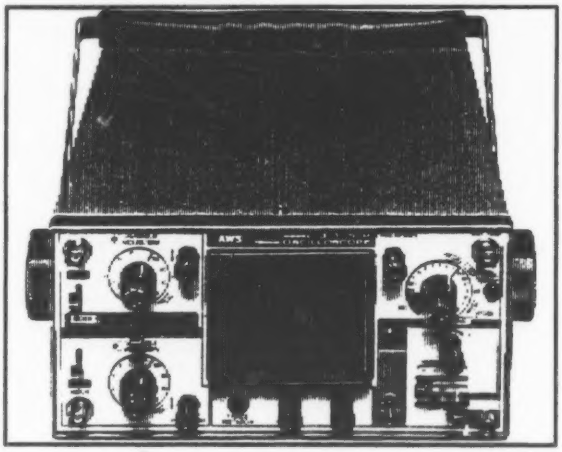


Fig. 5. Dual channel oscilloscope. (Courtesy of A.W. Sperry)

When looking at the screen on the scope, the vertical direction is voltage and the horizontal direction is time. Time can be either period or frequency. In figure 7, one sine wave is shown on the face of the screen. Notice how the action of the signal input and the horizontal sweep results in a display of the signal on the screen of the scope.

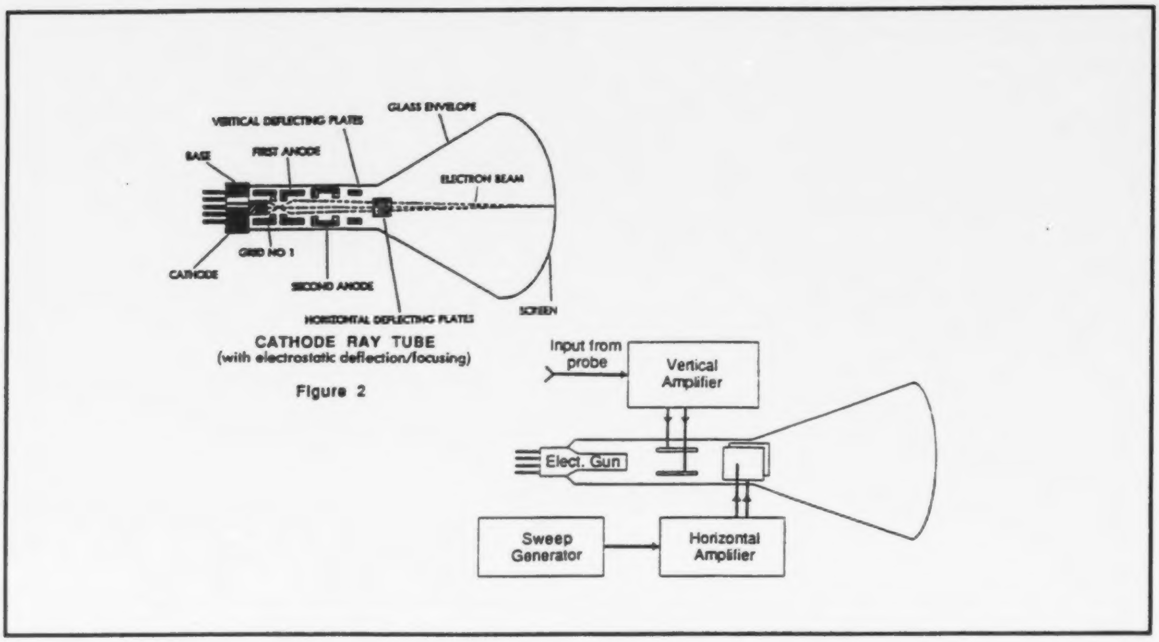

VERTICAL DEFLECTING PLATES
GLASS ENVELOPE
BASE
FIRST ANODE
ELECTRON BEAM
GRID NO 1
CATHODE
SECOND ANODE
HORIZONTAL DEFLECTING PLATES
SCREEN
CATHODE RAY TUBE
(with electrostatic deflection/focusing)
Figure 2
Input from probe
Vertical Amplifier
Elect. Gun
Sweep Generator
Horizontal Amplifier

Fig 6. Block diagram of the basic parts of an oscilloscope

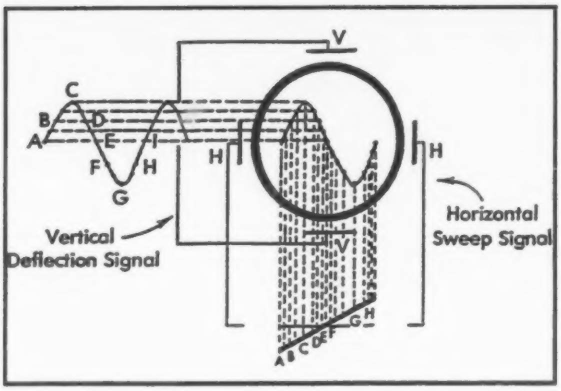

V
C
B
D
A
E
I
F
H
G
H
H
Vertical Deflection Signal
Horizontal Sweep Signal
V
A B C D E F G H I

Fig. 7. Cathode ray tube

The Time/Division control on the scope, as shown in figure 5, controls the time for the horizontal sweep and should be adjusted to put the desired waveform on the screen. The Volts/Div control sets the amount of amplification of the vertical amplifier for the vertical part of the trace on the screen.

The trigger control on the scope is designed to set the trigger point that triggers the horizontal sweep to operate at the start of each waveform. This will hold a picture of the waveform on the screen. The brightness and focus are used to adjust picture quality.

Examine figure 8, and notice the sine wave shown on the face of a scope screen. If you assume that the Time/Division control is set at 20 ms per division, you can calculate the frequency of the signal shown on the screen.

First, you count the number of divisions for one cycle or one wave. Starting on the left side, there is 0.4 of one division plus an additional 5 division and then another 0.4 divisions for a total of 5.8 divisions. The time for one wave is 5.8 times the 20 ms, or 116 ms. This 116 ms is the period of the wave. You can use your calculator to invert this according to the formula given at the beginning of the assignment and get 8.6 kilocycles or 8.6 kilohertz. The term *hertz* is the modern way of saying cycles per second. The abbreviation for hertz is *Hz*.

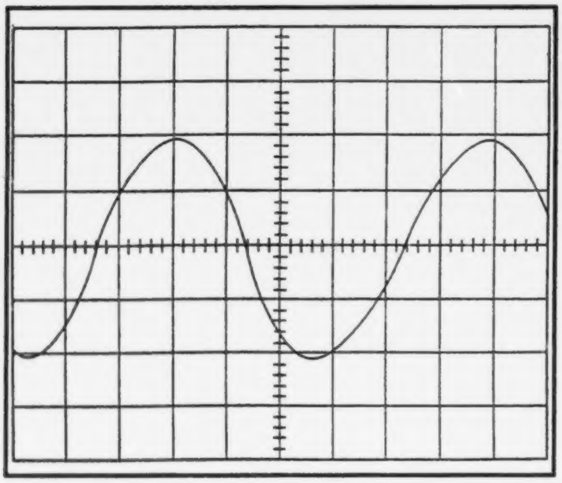


Fig. 8. Sine wave shown on oscilloscope

If the Volts/Div control is set at 1 volt per division, then you can count the divisions from the top of the waveform to the bottom to find the voltage of the signal. There are 4 divisions from the top to the bottom, which is 4 volts. This is 4 volts peak-to-peak. This would be 2 volts peak or 1.4 volts rms.

Most quality scopes are dual channel. This means they can display two signals at once on the one screen (see fig. 9). The Time/Div control is common to both signals, and there is a separate Volts/Div control for each channel.

If you assume that the controls have not been changed from your previous example, and that both Volt/Div controls are on 1 volt per division, then both signals are 2 volts peak-to-peak. They are both the same frequency; however, they are not in phase. There is a difference of one division between the points where they cross the same horizontal line. Since there are about 5.5 divisions for one wave on each signal, this results in 1/5.5 times 360 degrees, or the two signals are approximately 65 degrees out of phase with each other.

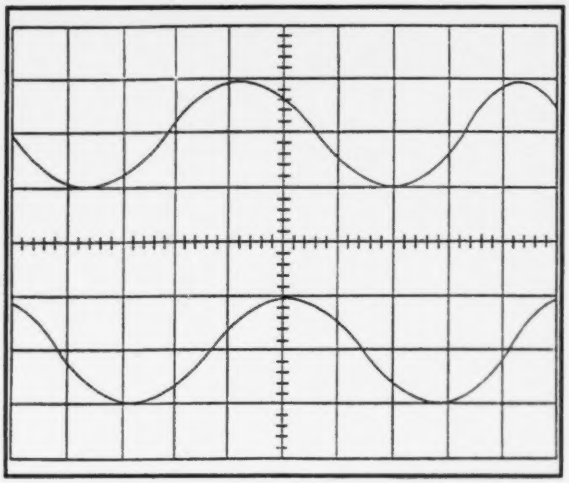


Fig. 9. Two signals shown on a dual channel oscilloscope

Self-Test

1. In figure 9, if the Volts/Div control is set to 50 mV per division, what is the rms voltage of the two signals?
2. In figure 9, if the Time/Div control is set to 5 ms per division, what is the frequency of the two signals?

Capacitors

There are numerous capacitors in most automobiles. Capacitors have been used across the points in the older style ignition system for many years. They have also been used to filter out ignition noise from radios on many vehicles.

When working with the electronics in automobiles, you will work with capacitors that have a specified amount of capacitance designed into them and capacitance in components and wires where it is not planned. Capacitance is the ability to store electrons by using an electrostatic field. The electrostatic field is caused by electrons at rest and behaves in a similar manner to a magnetic field.

The concept of a capacitor can be illustrated by the simple capacitor in figure 10. It consists of two conducting plates separated by an insulator, called a *dielectric*. Any time two conducting plates are separated by an insulator, you have a capacitor.

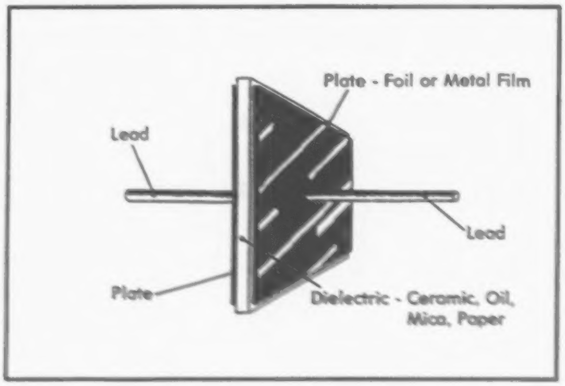


Plate - Foil or Metal Film
Lead
Lead
Plate
Dielectric - Ceramic, Oil, Mica, Paper

Fig. 10. A simple capacitor

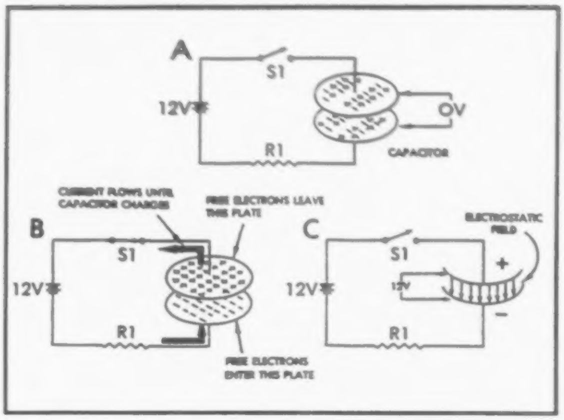

A
S1
12V
0V
R1
CAPACITOR
CURRENT FLOWS UNTIL CAPACITOR CHARGES
FREE ELECTRONS LEAVE THIS PLATE
B
S1
12V
R1
FREE ELECTRONS ENTER THIS PLATE
C
S1
12V
12V
ELECTROSTATIC FIELD
+
−
R1

Fig. 11. Charging a capacitor

You can see how the capacitor works by referring to figure 11. Notice that you are using actual electron flow instead of conventional current flow in this example. Figure 11 uses air for the dielectric material, and part A shows the switch open, resulting in no current flow into the capacitor. If you put a meter across the capacitor, the meter would read 0 volts as shown.

When the capacitor shows no charge on it, as it does in part A, this means the number of electrons on both plates is equal. In part B, the switch is closed, allowing current to flow. Although there is an insulator separating the two plates, current will flow until the difference in the number of electrons on each side equals the voltage of the source. If there is very little or no resistance in the circuit, charging the capacitor will be almost instantaneous.

Part C in figure 11 shows the capacitor fully charged to the source voltage. Notice that the charge remains after the switch is opened. Capacitors do have some leakage, which will cause the charge on the capacitor to dissipate after awhile.

The amount of charge a capacitor can hold is called its capacitance and it is measured in farads. One farad is equal to the flow of one ampere for one second into a capacitor, which results in one volt across the capacitor. This is more capacitance than is normally used in most circuits. Most capacitors that you will see in automotive applications will be rated in *microfarads* (*μF*).

There are three ways to change the amount of capacitance in a capacitor. Increasing the size of the plates (fig. 12) or reducing the distance between the plates (fig. 13) will increase the capacitance. Changing the material used to make the dielectric will increase or decrease the capacitance (fig. 14).

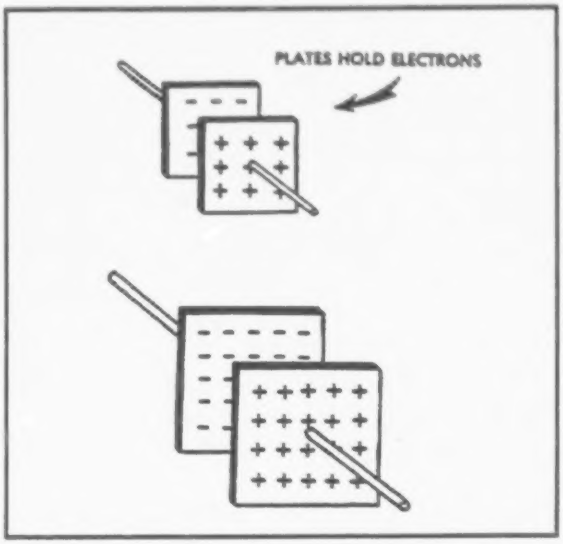

PLATES HOLD ELECTRONS

Fig. 12. Enlarging increases capacitance.

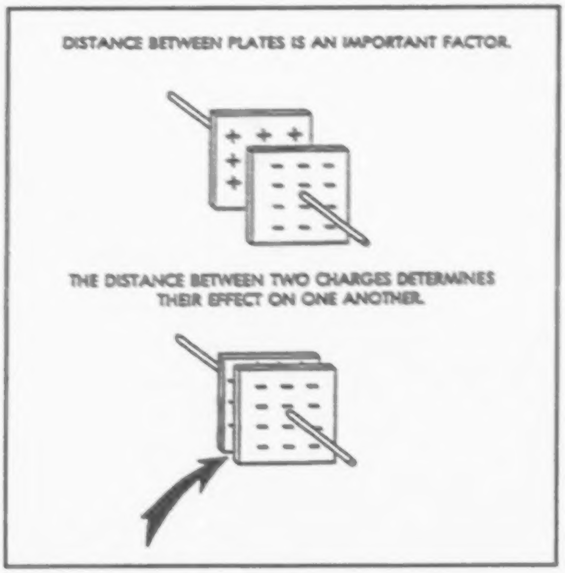

DISTANCE BETWEEN PLATES IS AN IMPORTANT FACTOR.
THE DISTANCE BETWEEN TWO CHARGES DETERMINES THEIR EFFECT ON ONE ANOTHER.

Fig. 13. The closer the plates are to each other, the greater is the capacitance.

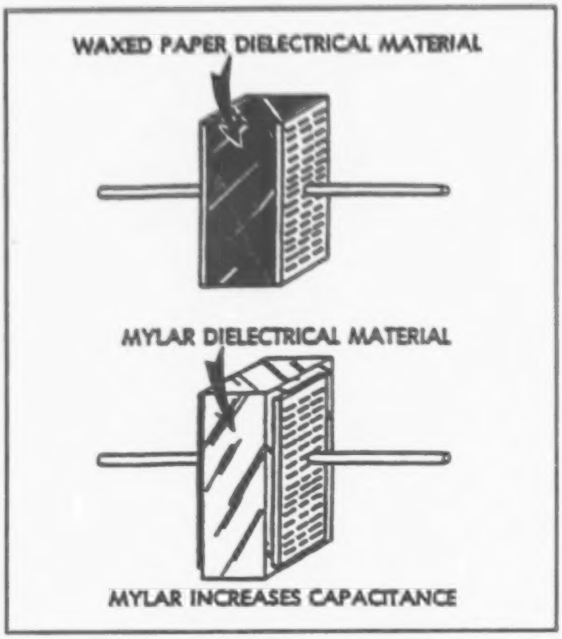

WAXED PAPER DIELECTRICAL MATERIAL
MYLAR DIELECTRICAL MATERIAL
MYLAR INCREASES CAPACITANCE

Fig. 14. Different dielectric materials raise or lower capacitance.

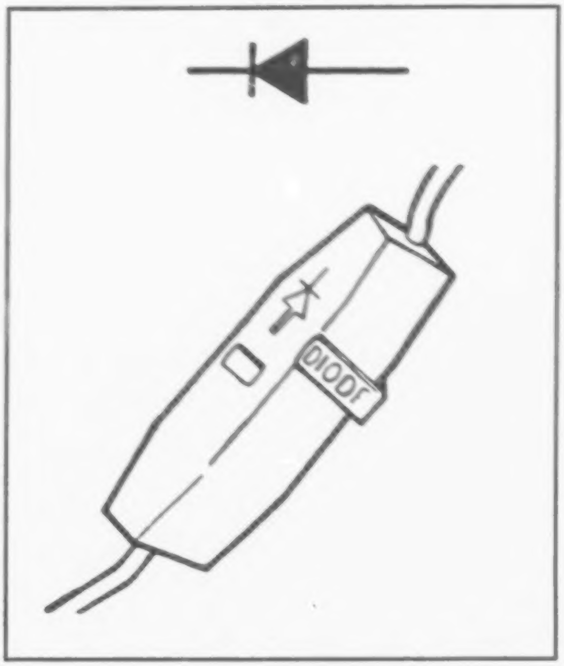


Fig. 15. A typical diode and its symbol

Capacitors will appear in many different sizes and shapes in the automotive environment. Figure 15 shows a typical capacitor and the symbol that most automotive manufacturers use in their schematics. Figure 16 shows the symbol for a capacitor that is used in most electronic publications.

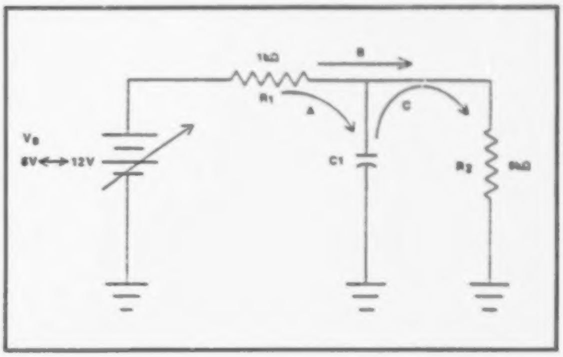


Fig. 16. A circuit with a capacitor

You can use figure 16 to see how a capacitor affects a circuit. The voltage source has an arrow through it, which means it is varying in voltage output. V_S shows that it is varying from 6 to 12 volts and back again. With the circuit as shown, when the voltage is increasing from 6 volts to 12 volts, part of the current is going into the capacitor, and part is going on to the resistance R_2. The resistance between the capacitor and the voltage source allows the capacitor to have a different voltage drop across it than the voltage source. When the voltage source is dropping in voltage, the current will be coming out of the capacitor, feeding both the load and the voltage source. As a result of this action from the capacitor, the voltage across the load will remain more constant than the voltage from the source.

This characteristic of capacitors allows them to be used to smooth out fluctuations in voltage that can be harmful to other components. They are used to reduce high-voltage spikes known as spark plug noise and to reduce the spark across switch contacts. You will often find a capacitor connected from the 12-volt supply line in a sound system to the chassis of the vehicle, to eliminate noise in the final audio.

Self-Test Answers

1. *The voltage peak-to-peak is 100 mV. Divide this in half to get a peak value of 50 mV. You then multiply this 50 mV by 0.707 to get the rms value of 35 mV.*

2. *Count the number of divisions, and multiply that by the 5 ms, which will give you the period. Use your calculator to invert the period (1/X) to get approximately 36 kHz. Note: a higher level of accuracy could be obtained by adjusting the Time/Div control to put only one wave on the screen.*

Summary

The common alternator in an automobile generates ac current as a result of mechanically turning the armature in a magnetic field. Each full revolution of the armature is 360 degrees and is also one wave. The ac current that comes from an alternator is in the form of a sine wave. The time required for one sine wave, or a full 360 degrees, is the period of the wave. The period of the wave is equal to the frequency of the wave inverted.

An ac sine wave has a peak-to-peak voltage, which is the voltage from the top of the wave all the way to the bottom of the wave. The peak value is half of this or the voltage from the center of the wave to the maximum either top or bottom. The amount of voltage that will de amount of work as a dc signal is the rms voltage and is equal to 0.707 times the peak value of a sine wave.

You can use the oscilloscope to find the frequency of a signal by determining the period of the wave from the time it takes to make one wave and mathematically inverting it. The oscilloscope or scope shows the signal voltage vertically and the time horizontally.

You can also use the scope to compare the phase difference between signals. Two signals of the same frequency can reach their maximum voltage at different times. This difference in phase between the two signals is usually expressed in degrees.

The capacitor is simply two conducting plates separated by an insulator, called the dielectric. It is used to store an electrical charge on the plates of the capacitor. The capacitor's ability to store and release current is used to smooth out variations in voltage. It suppresses noise and other voltage spikes in the automobile and reduces arcing across contacts in switches and the ignition system.

Exercise

1. What is the frequency of a sine wave that takes 20 ms to complete 6 cycles or waves?
2. What is the dc voltage equivalent of a 15-volt peak voltage when you are talking about the amount of work the voltage can do?
3. If one sine wave on the screen of an oscilloscope takes 4.3 horizontal divisions and the Time/Div control is on 5 ms per division, what is the frequency of the signal?
4. Two signals on a dual trace scope each take 6.5 divisions horizontally for one wave and are 0.8 division different at the point they cross the center line. How many degrees are they out of phase?
5. What three things will influence the capacitance of a capacitor?

C-6 AC and Computer Signals

Laboratory Experiment

Essential Elements: **(gg) (1-3)**

Objective

In this lab, the student will examine the properties of capacitors.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 100 mF or higher capacitor
2 resistors; 1 kΩ and approximately 9 kΩ
1 DVOM

Procedure

The capacitor should have a voltage rating that equals the 6-volt source or greater. The electrolytic capacitors are sensitive to the polarity of the voltage they are connected across. On the side of the capacitor there will be a plus sign and a minus sign showing which lead to connect to the positive and negative parts of your circuit. The voltage source should have the positive lead connected to resistor R_1, and the capacitor should have its positive lead connected to the other side of R_1. The capacitor may burst and throw pieces of material and chemicals if it is installed backwards. It will also burst if the voltage rating on the capacitor is less than the voltage in the circuit.

Caution: Protect your eyes from the capacitor bursting: wear goggles or other eye protection.

Redraw figure 1 on a separate piece of paper or your notebook. Pick out two resistors with values from 20 to 50 kΩ, and show these values on your drawing. You will duplicate the switch by connecting and disconnecting your jumper when you build the circuit.

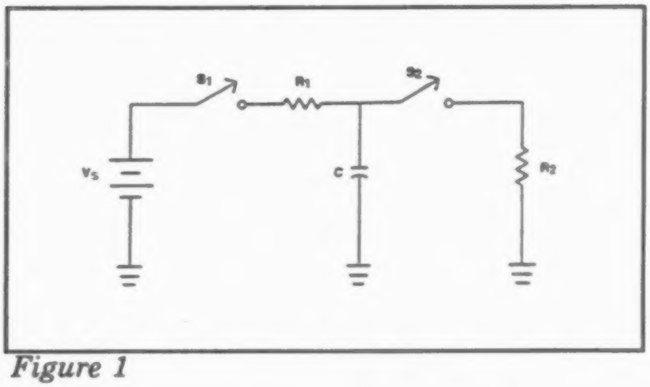


Figure 1

1. Build the circuit in figure 1. Connect both switches, and use your DVOM to measure the voltage source. Record that voltage value on your paper.

2. Since both resistors are the same value, the voltage across the capacitor will be half of the voltage source. Measure this voltage, and verify that it is half of the source voltage.

3. Use the jumpers to connect your meter across the capacitor. You will need to have a watch or other timepiece handy. Open switch S_1 and wait until the voltage across the capacitor has dropped to zero. Now open switch S_2 and then close switch S_1.

   Record the time it takes for the voltage across the capacitor to increase to the voltage of the voltage source.

4. Open both switches, and notice that the voltage across the capacitor drops very slowly, if at all. There is probably some leakage in the capacitor. Different capacitors will have different amounts of leakage.

5. Close switch S_1 until the capacitor is fully charged again, and then open S_1 and close S_2. Record the time it takes for the capacitor to discharge completely.

C-7

Semiconductor Diodes

Essential Elements: (gg)(1-3)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how diodes operate*
- *explain electronic components*
- *explain wire and connector repair*

Semiconductor Theory

Semiconductor devices allow us to control electric current. This control takes many different forms. The *diode* allows current to only flow one way. The *transistor* uses a small amount of current to control a much larger amount of current. The *field-effect transistor* uses voltage to control current.

Both germanium and silicon can be used to make semiconductor devices, but silicon is most commonly used. Silicon has four electrons in its outer orbit. Remember that a full outer orbit of any substance is eight electrons, and a good insulator will have the full eight, and a good conductor will have only one electron in the outer orbit. Silicon with four electrons in its outer orbit is therefore a semiconductor, or halfway between a good insulator and a good conductor.

The atomic structure of silicon allows its conductivity to be increased by adding impurities. The process of adding impurities is called *doping*. Doping increases the conductivity by adding extra charges to the silicon.

When an impurity with five extra electrons in its outer orbit is added to the silicon and allowed to bond with the silicon, the extra or fifth electron results in a negative ion or negative-type material. This silicon with the extra electrons is then N-type material. If an impurity with three electrons is bonded with the silicon, a deficiency of electrons will result and the silicon becomes P-type material.

N-type material and P-type material have extra free charges that can be moved by an external voltage. When P-type material and N-type material meet, a PN or NP junction is formed. This junction has opposite free charges on opposite sides of the junction. The junction is the useful part of any semiconductor device because the junction voltage controls the flow of current.

A simple PN junction with leads coming from the P-type and N-type material is a diode, and it will allow current to flow in only one direction.

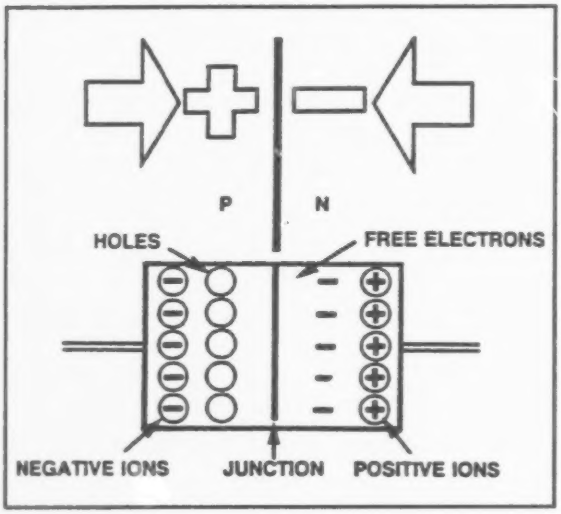


Fig. 1. Unlike charges attract.

The P-type material has a deficiency of electrons or holes where an electron would be, and the N-type material has an excess of electrons as shown in figure 1. When these two different types of material are brought together, some of the electrons from the N-type material jump over and fill the holes on the P side of the junction. This leaves atoms without electrons on the N side and atoms with electrons on the P side. The result is negatively charged atoms or ions on the P side and positively charged ions on the N side.

As shown in figure 1, we end up with a junction that becomes a barrier to any further flow of electrons. When a voltage source is connected across the diode junction as shown in figure 2, if the voltage is high enough, the pressure of the voltage will push the electrons through the junction, and current will flow. For most ordinary silicon diodes, the voltage has to be 0.7 volt to push electrons through the diode.

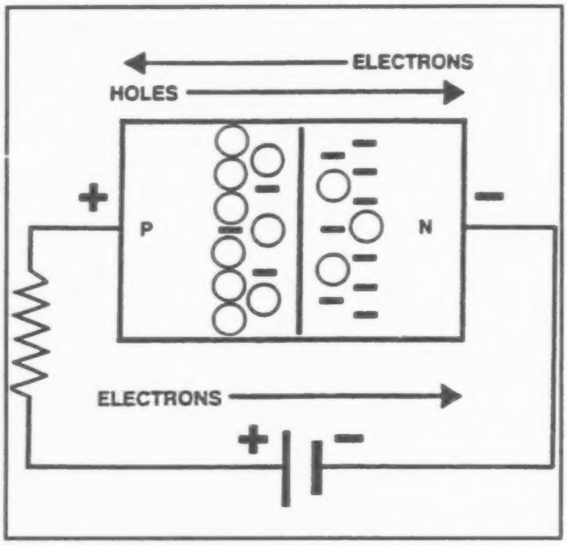


Fig. 2. Like charges repel.

When the voltage source has its negative terminal connected to the N-type end of the diode and the positive terminal to the P-type end, it is forward-biased, and current will flow when the voltage is 0.7 volt. The voltage will not be over 0.7 volt, since there is very little resistance to current flow with higher voltages. The low resistance that a diode has to current flow when the voltage exceeds 0.7 volt will result in high current which will destroy the diode.

When the electrons flow through the junction of a diode, they give up energy in the form of light and heat. Since the light is usually infrared or ultraviolet and the case around the diode is opaque, we do not see the light. If there is too much current flow through the diode, we will feel the heat unless the diode fails first. This ability of the diode to give off light is used to make *light-emitting diodes* (LEDs). You will study LEDs later.

The symbol for a diode is the arrow with a bar across the tip, as shown in figure 3. Note that forward biasing the diode results in conventional current flow with the arrow.

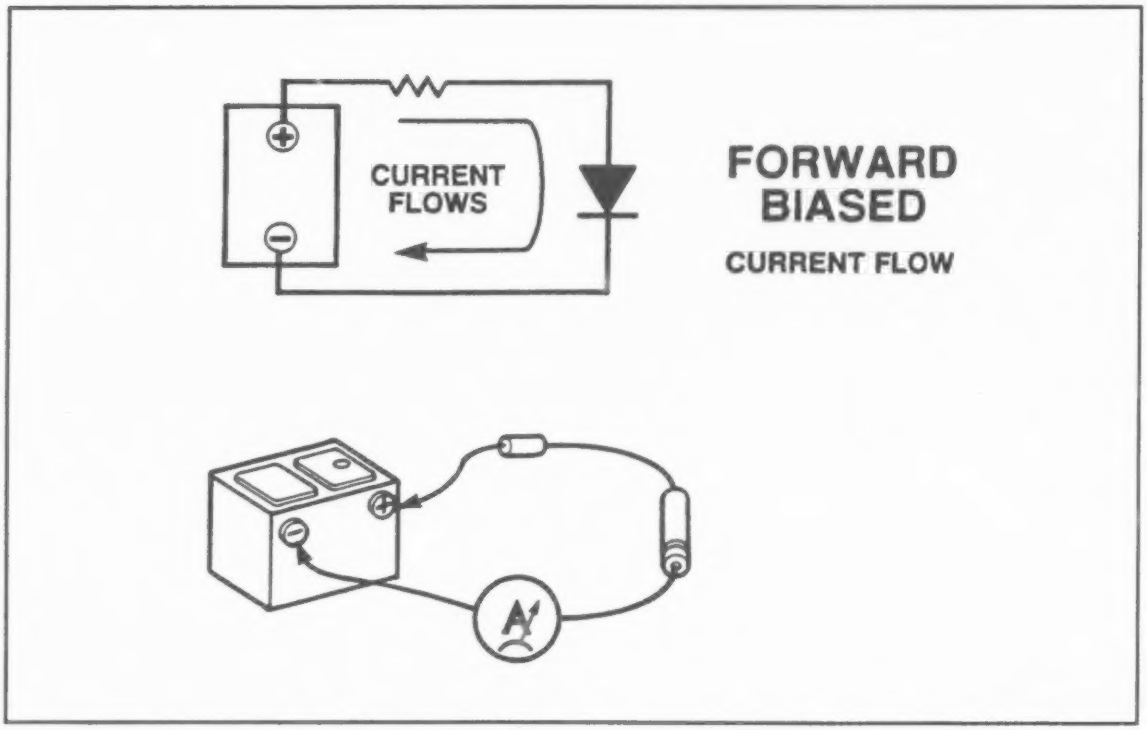


Fig. 3. Forward-biased current flow

Figure 3 shows a resistor in series with the diode. This resistor is used to limit the current flow through the diode. Some kind of resistance or resistor must always be used in series with a diode to limit current flow, or the diode will be destroyed.

When you reverse the voltage source connections to the diode (fig. 4), the electrons move away from the junction. The junction increases in size with the amount of reverse voltage applied, but no current flows. The voltage can be increased until breakdown occurs and current flows; however, for ordinary diode operations, this voltage should never be reached. The zener diode, which you will look at later, uses this breakdown to control the voltage level.

The most common use for diodes in the automobile is to change the alternating current (ac) from the alternator to direct current (dc) for use in the automobile. Figure 4 shows what these diode packages look like. The alternator will use six or more diodes to change the ac to dc. The bridge package has six diodes in it, and the trio package has three diodes in it.

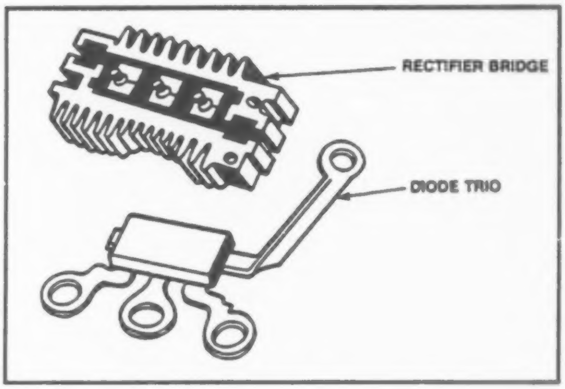


Fig. 4. Integrated diode types

You will study the alternator in more detail later; however, figure 5 shows how the diodes are arranged to direct the flow of current from the coils in the alternator.

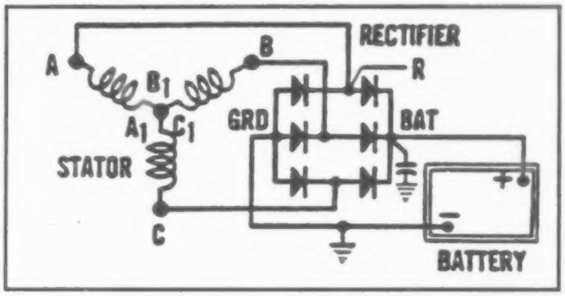


Fig. 5. Diode rectifier assembly in a three-phase alternator

Current will flow in both directions from each one of the coils in turn. You can trace out the flow of current using the diodes and notice how the flow always ends up going to the positive terminal of the battery.

Zener Diode

The zener diode has been designed to take advantage of the reverse voltage breakdown that all diodes will experience with enough reverse voltage. By changing the amount of doping in the P-type and N-type materials, the ability of the junction to hold the reverse voltage can be changed. This allows the manufacturer to build diodes with reverse voltage breakdown voltages that are useful for maintaining a reference voltage.

The graph in figure 6 shows the current flow for the full range of voltages of a diode.

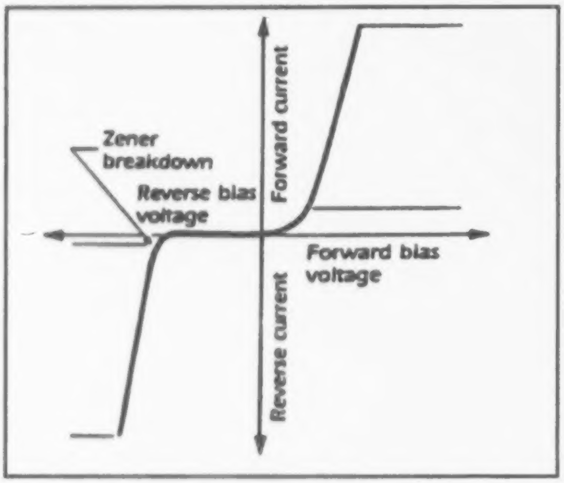


Fig. 6. Zener diode operation

The voltage increases from zero at the vertical line in the center, going positive to the right and negative to the left. The current increases in the forward direction going up from the center horizontal line, and is reverse-bias or in the reverse direction going down from the center line. If you start where the two graph lines cross, which is zero volts and zero current and move to the right, you see the thick line move along at zero current for a short distance and then turn up. This line shows that the diode has no current flow until it has 0.7 volt across it, at which time current starts to increase.

Going back to the point of zero current and zero volts, where the lines cross, you can go to the left or reverse-bias the diode. Notice that you go a lot further or a lot higher reverse voltage before the current starts to flow. Now the current flows against the arrow on the zener symbol. Like the forward current condition, there is little resistance to the flow of current, and some resistance will have to be in the circuit to keep the current from burning up the diode.

The schematic symbol for the zener diode is shown in figure 7. *Anode* and *cathode* are terms for the different ends of the diode. The line across the point of the zener was originally the letter *Z* for zener.

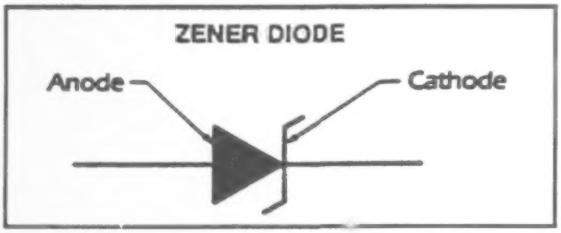


Fig. 7. Zener diode symbol

If you use a zener rated at 5 volts, has a breakdown voltage of 5 volts, you can put a resistor to limit the current and use it as a regulator (fig. 8).

This circuit in figure 8 will take any voltage from 10 to 15 volts or more on the input or left side and provide a regulated 5 volts coming out of the right side.

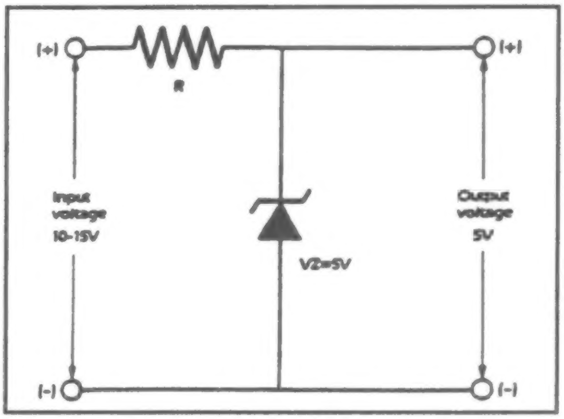


Fig. 8. Zener diode used in circuit to prevent spikes in voltage

The zener is used in the regulator circuit in many alternators to sense the voltage level and adjust the current level into the alternator to hold the required voltage level from the alternator. You will study this in more depth when you study the charging system.

Light-Emitting Diode

As you learned earlier, when the electrons are pushed through the junction of a diode, they will release heat and light. The light-emitting diode (LED) is made using different materials to cause it to give off light in the visible spectrum. By changing the materials that are put into an LED, different colors can be achieved. These different materials also change the junction voltage from 0.7 volt to a voltage between 1.5 volts and 2.5 volts.

When working with LEDs, most technicians assume a voltage drop of 2 volts in their calculations. The typical off-the-shelf LED will have a maximum current capacity of 20 mA. Although some can handle 30mA, it is safer to assume a maximum of 20 mA and calculate based on a typical usage of 15 mA.

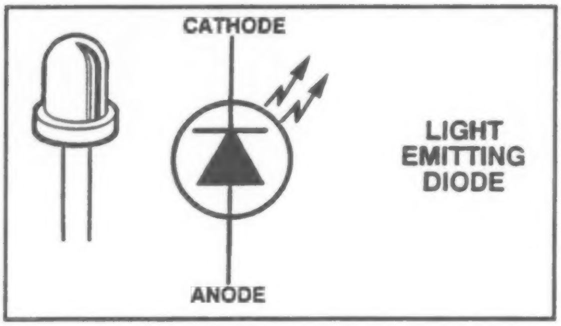


Fig. 9. Light-emitting diode and its symbol

The schematic symbol for the LED has a little more added to the standard diode symbol as shown in figure 9. The terms *anode* and *cathode* take on more importance with the LED. When LEDs are packaged as a seven-segment display, their polarity can be either common anode or common cathode.

A handy test light can be made using an LED and a series resistor to limit the current through the LED. An automobile has a maximum of 12 volts in the system. We can design a test light based on this 12-volt maximum (fig. 10).

Since the test light may be used for voltages less than 12 volts, we should design for the maximum current flow at 12 volts. According to the formulas in figure 10, the source voltage (V_S), which is 12 volts, minus the voltage drop across the LED (V_{LED}) will equal the voltage drop that we should have across the series resistor (V_R). This is 12 V - 2 V = 10 volts. The current-limiting resistor should have 10 volts across it.

Now, you can take this 10 volts and, using the next formula in figure 10, divide the 10 volts by the LED current (I_{LED}).

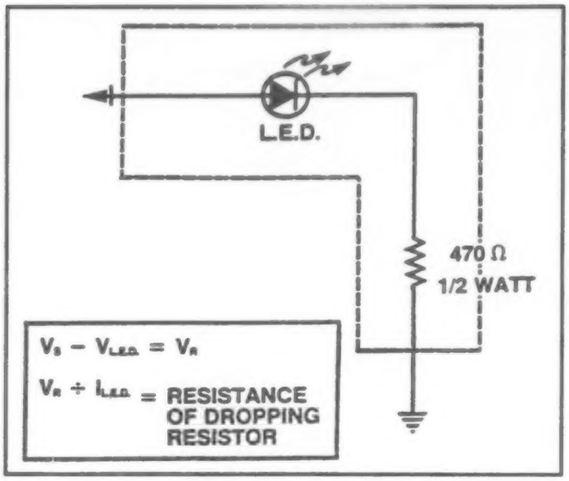


Fig. 10. Low-current, 12-volt test light

In this case, you will use the maximum current since you want this light to work with lower voltage levels. The 10 volts divided by 20 mA gives 500 ohms. The nearest 5% resistor to 500 ohms is the 470-ohm resistor shown in figure 10.

The most common usage for LEDs in the automobile is for signal lights, like the stereo light on the radio. They are also used to sense the position of something based on reflecting the light from an LED to a device that will turn on in the presence of light. The seven-segment LED, which displays letters and numbers, is used for warning messages and information display on the dash. Since strong sunlight can make an LED display hard to see, additional circuitry increases the current to the display and makes it brighter when it senses strong light.

Figure 11 shows how the diodes are arranged for a common anode LED display. Notice that the anodes on all the diodes are connected together and come out on one pin. The cathodes are brought out individually to light up as necessary for the particular number. When replacing an LED display, be sure that you have either the common anode or common cathode, depending on the design of the circuit. The wrong one will reverse-bias the diode, and no current will flow, resulting in no display.

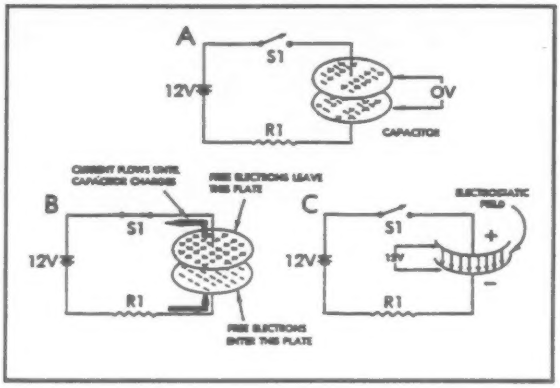

A
S1
12V
0V
R1
CAPACITOR
CURRENT FLOWS UNTIL CAPACITOR CHARGES
FREE ELECTRONS LEAVE THIS PLATE
B
S1
12V
R1
FREE ELECTRONS ENTER THIS PLATE
C
S1
ELECTROSTATIC FIELD
+
12V
12V
−
R1

Fig. 11. Seven-segment LED

Hall Effect

There are numerous magnetic sensors in the modern automobile. Most of the electronic ignition systems sense the position of the engine using magnetic sensors based on the Hall effect.

When a magnetic field is impressed on N-type semiconductor material with current flowing at right angles to the magnetic lines of force, a voltage will appear across the semiconductor material. This phenomenon is used to make semiconductor magnetic sensors, or Hall effect devices. Remember, some current has to be flowing in the device for it to work, and the orientation of the magnetic field is important.

The combination of small magnets and the Hall effect devices on individual wheels can be used to sense the relative speed of each of the wheels on a car. Figure 12 shows the solid-

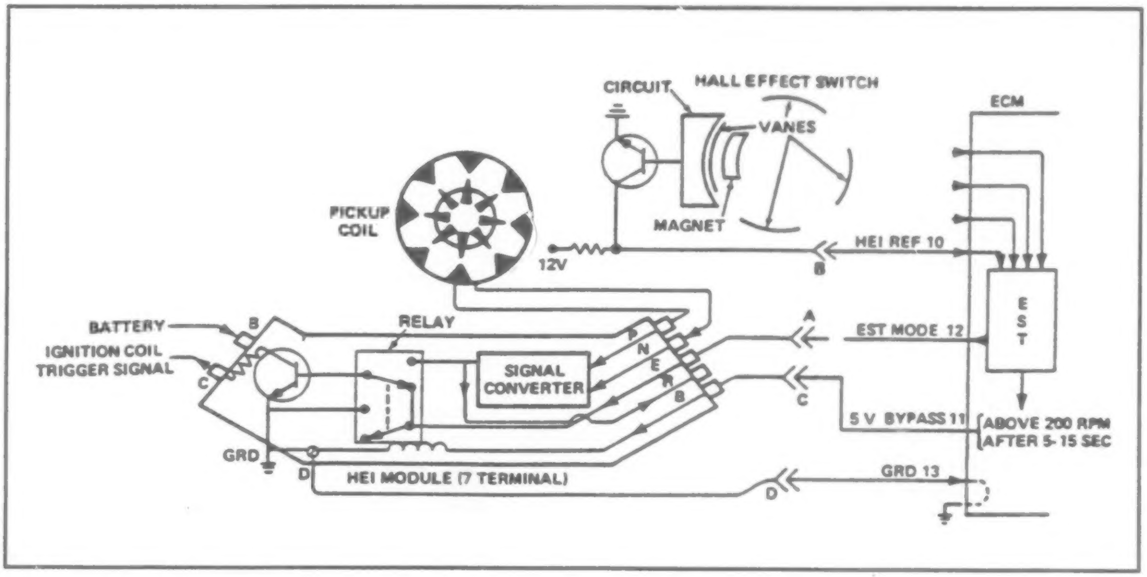

CIRCUIT
HALL EFFECT SWITCH
VANES
MAGNET
ECM
PICKUP COIL
12V
HEI REF 10
B
E
S
T
BATTERY
B
IGNITION COIL TRIGGER SIGNAL
C
RELAY
SIGNAL CONVERTER
P
N
E
R
B
A
EST MODE 12
C
5 V BYPASS 11
ABOVE 200 RPM
AFTER 5-15 SEC
GRD
D
HEI MODULE (7 TERMINAL)
GRD 13
D

Fig. 12. Hall effect sensor in circuit

state ignition system for General Motors cars. The iron vanes shown interrupt the magnetic force when they pass between the magnet and the Hall effect device.

Silicon-Controlled Rectifier

The silicon-controlled rectifier (SCR) is a diode that will only conduct after it has been switched on. Notice that the symbol for the SCR (fig. 13), has three leads going to it. The lead labeled *gate* will turn on the SCR. A momentary voltage applied to the gate will turn on the SCR, and it will stay on after the voltage is removed from the gate. The current through the SCR has to be interrupted before the device will turn off. The SCR is becoming more popular in automotive applications. General Motors is using them in their "Posipower System," and some vehicles with emergency backup batteries use them to switch batteries.

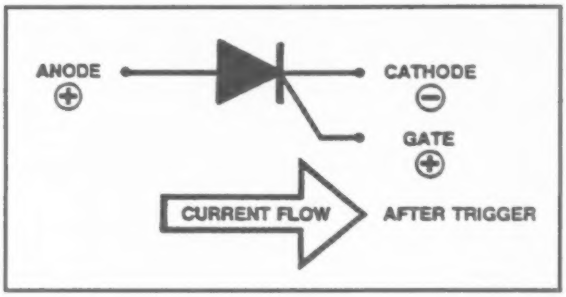


Fig. 13. Silicon-controlled rectifier (SCR) and symbol

Summary

Diodes and transistors are made using semiconductor material. The important part of the diode or transistor is the junction between the N-type and P-type material. This N-type or P-type material is made by adding impurities to silicon. The impurities either add or subtract an electron, giving the material its positive or negative characteristics. For ordinary silicon diodes, the junction between the N-type and P-type material will have a 0.7-volt drop across it when it is forward-biased. No current will flow under normal conditions when the junction is reverse-biased.

When electrons flow through a PN or NP junction, they give off energy in the form of light and heat. If too much current passes through the junction, the heat will damage the device. Light-emitting diodes take advantage of the generation of light by having a clear coating over the junction. The LED is normally made with other materials besides silicon to give off light in the visible part of the spectrum. Because of the other materials, the voltage drop for an ordinary LED will be around 2 volts.

If the reverse-bias voltage across a diode is high enough, the diode will break down and current will flow. The point where the diode breaks down is called the breakdown voltage or the zener voltage. This property of diodes is used to make zener diodes which are used as voltage regulators.

The Hall effect will result in a voltage across a semiconductor material when a magnetic field is present and there is current flow. This is used to make magnetic sensors to sense the position of various parts of the engine and wheels on a car.

Exercise

1. How many electrons does silicon have in its outer orbit?

2. What is the voltage drop across a PN junction in silicon?

3. What will happen if you forward-bias your LED by putting it directly across your 6-volt battery pack?

4. What size of series resistor would be required in the circuit to limit the current in a typical LED if the voltage source is 14 volts?

5. If the circuit puts a positive voltage at the common point for a seven-segment LED, what kind of seven-segment LED is it?

6. What is the maximum current that most off-the-shelf LEDs can handle?

7. How is an SCR switched off?

C-7 Semiconductor Diodes

Laboratory Experiment

Essential Elements: (gg) (1-3)

Objective

In this experiment, the student will examine the properties of diodes.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 silicon diode
1 light-emitting diode
1 1 kΩ resistor and 1 330 Ω resistor (5% 1/4 watt)
1 DVOM

Procedure

The diode can be identified by examining figure 1. Notice that the black band around the body of the diode corresponds to the line across the tip of the symbol of the diode.

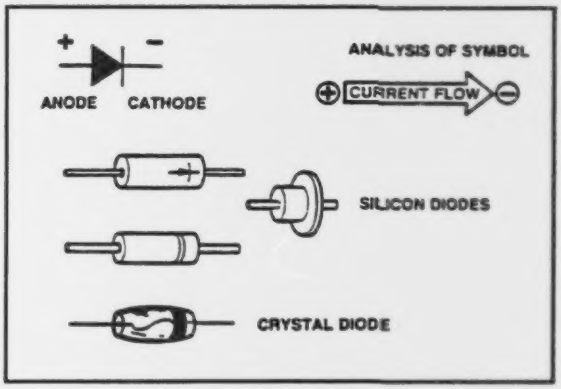

+
−
ANODE
CATHODE
ANALYSIS OF SYMBOL
⊕ CURRENT FLOW ⊖
SILICON DIODES
CRYSTAL DIODE

Fig. 1. Discrete components

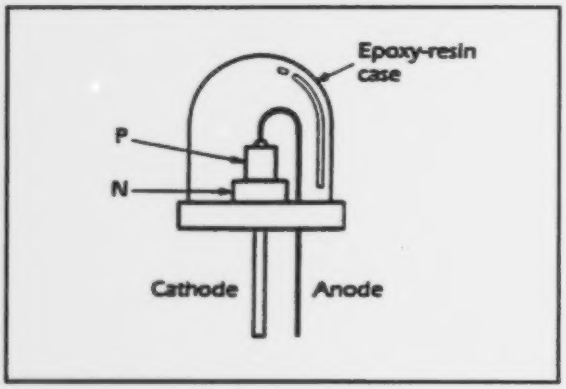

Epoxy-resin case
P
N
Cathode
Anode

Fig. 2. Light-emitting diode

Identifying the proper leads on an LED will be a little harder (fig. 2). Sometimes it is necessary to simply put it in the circuit and, if it doesn't light, turn it around.

1. Use your jumper leads to build the circuit in figure 3. The voltage source should be your 6-volt battery supply. Use the 330 Ω resistor in series with the diodes as shown. If the LED doesn't light, turn it around. The switch can be your connecting and disconnecting the jumper leads.

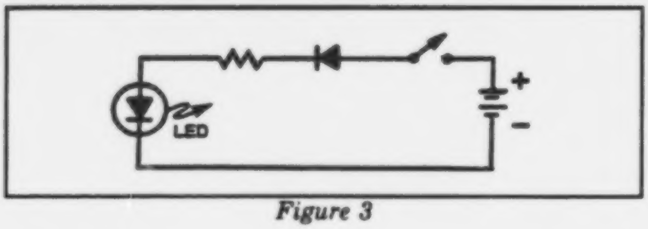


Figure 3

2. Use your DVOM to measure the voltage drop across the LED and across the silicon diode. Record these voltages in your notebook or other paper.

3. Measure the voltage drop across the resistor, and calculate the current for the circuit. Record this value in your notebook or paper.

4. Turn the diode around, and measure the voltage drop across the resistor. There should not be any voltage drop since there is no current flowing when the diode is reverse-biased.

5. Turn the diode around so it is forward-biased, and replace the 330 Ω resistor with the 1 kΩ resistor. Notice that the LED is much dimmer. Measure and record the voltage drops across the two diodes and the resistor. Compare these readings with the readings that you took earlier. Notice that the voltage drop across the diodes has changed only a little.

   The junction will have a certain voltage drop with all current levels, and the rest of the diode provides some resistance, which will make a small change in the voltage drop across the whole device.

C-8

Transistors

Essential Elements: (gg)(1-3)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how diodes operate*
- *explain how to use transistors as a switch*
- *explain the difference between bipolar and FET transistors*

Transistor Basics

The diodes that you studied in Assignment C-7 had P-type material joined to N-type material. This resulted in a PN junction. The previous lesson also told you that 0.7 volt is required to push electrons through a PN junction.

The bipolar transistor is similar in construction to a diode with an added junction. The common NPN transistor will have N-type material bonded to P-type material which is then bonded to N-type material. Although there are two PN junctions in a transistor, we are only concerned with one.

The schematic symbol for a common NPN transistor is shown in figure 1. Three types of transistors are shown beside the schematic drawing. The larger transistor shown is used for high current applications.

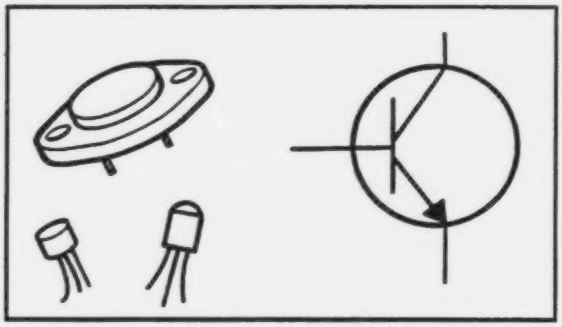


Fig. 1. An NPN transistor. (Courtesy of General Motors Corp.)

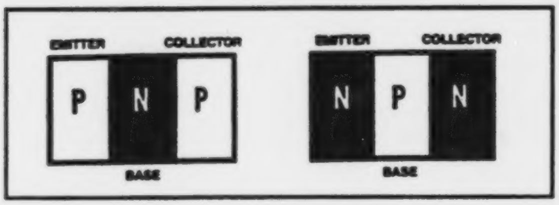

EMITTER
COLLECTOR
P
N
P
BASE
EMITTER
COLLECTOR
N
P
N
BASE

Fig. 2. PNP and NPN transistors. (Courtesy of General Motors Corp.)

Figure 2 shows the two ways that common bipolar transistors can be constructed. The one on the left is a PNP transistor, and the other one is an NPN transistor. The only difference between them is the direction of current flow. Figure 3 shows the schematic symbols for each of the transistors.

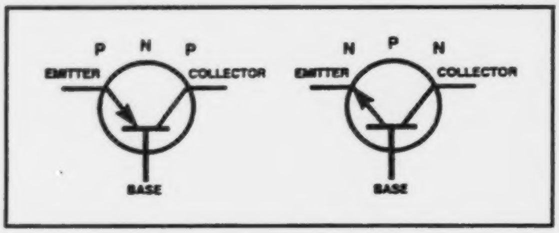

P
N
P
EMITTER
COLLECTOR
BASE
N
P
N
EMITTER
COLLECTOR
BASE

Fig. 3. PNP and NPN transistor symbols. (Courtesy of General Motors Corp.)

The arrow in figure 3 shows the direction of current flow according to conventional current flow. This means that the PNP transistor will have current flowing *out* the emitter, and the NPN transistor will have current flowing *into* the emitter of the transistor.

The base lead on the transistor is used to control the flow of current through the collector and emitter leads. For the NPN transistor, as shown in figure 4, when current is flowing into the base, there will be current flow into the collector lead and out the emitter lead.

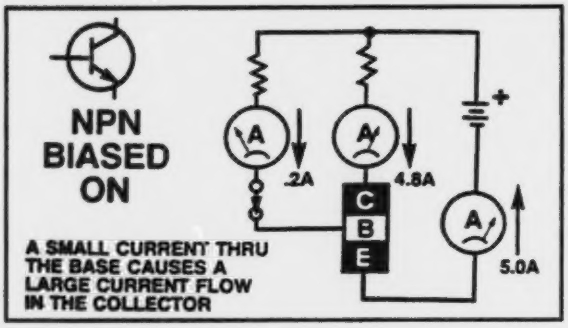

NPN
BIASED
ON
A
A
A
.2A
4.8A
5.0A
+
C
B
E
A SMALL CURRENT THRU THE BASE CAUSES A LARGE CURRENT FLOW IN THE COLLECTOR

Fig. 4. When the switch is closed, a small current flows from the base circuit to the emitter of an NPN transistor. (Courtesy of General Motors Corp.)

Notice that only a small amount of current flow into the base is sufficient to control the current flow through the collector and emitter leads. Our example in figure 4 has a current gain or beta of 25. In electronics, the beta of a transistor is the current gain. We can find the beta by dividing the emitter current by the base current (5 ÷ 0.2). Transistors designed for high current use will have current gains around 25. Transistors designed for low current applications often have current gains of 100 or more.

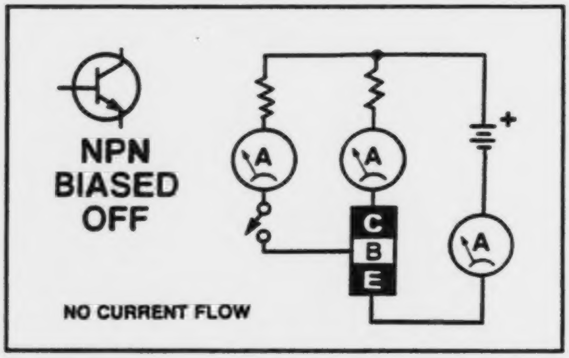

NPN
BIASED
OFF
A
A
A
+
C
B
E
NO CURRENT FLOW

Fig. 5. With the base circuit open, no current flows from the base circuit to the emitter. (Courtesy of General Motors Corp.)

Figure 5 shows the transistor with no current flow in the base. The lack of current flow in the base shuts off the current flow through the collector emitter junctions.

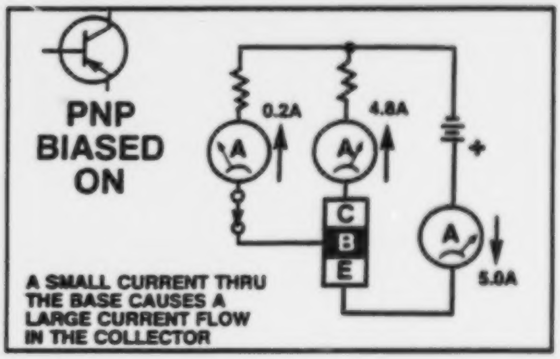

PNP
BIASED
ON
0.2A
4.8A
A
A
A
C
B
E
+
5.0A
A SMALL CURRENT THRU THE BASE CAUSES A LARGE CURRENT FLOW IN THE COLLECTOR

Fig. 6. With the switch closed, current flows from the base circuit to the collector in a PNP transistor. (Courtesy of General Motors Corp.)

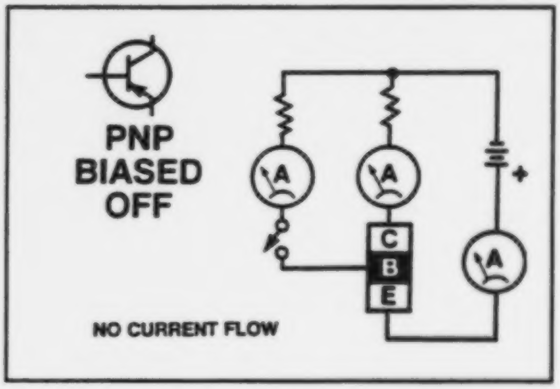

PNP
BIASED
OFF
A
A
A
C
B
E
+
NO CURRENT FLOW

Fig. 7. With the base circuit open, no current flows through the collector. (Courtesy of General Motors Corp.)

Figures 6 and 7 show a PNP transistor. The current gain is the same, only the direction of current flow has changed. The schematic symbol shows the direction of current flow for the transistor by the direction of the arrow on the emitter.

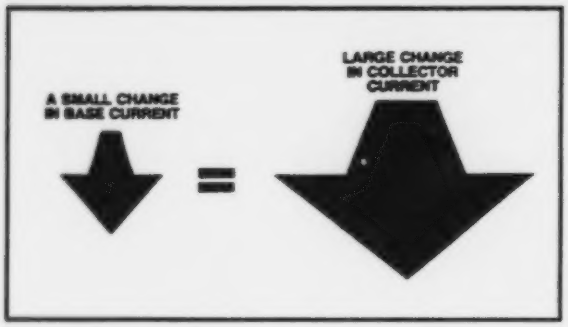

A SMALL CHANGE IN BASE CURRENT
=
LARGE CHANGE IN COLLECTOR CURRENT

Fig. 8. Amplifier current gain. (Courtesy of General Motors Corp.)

The amount of current flow in the base of a transistor will control the amount of current flow in the collector emitter junctions. This is shown in figure 9.

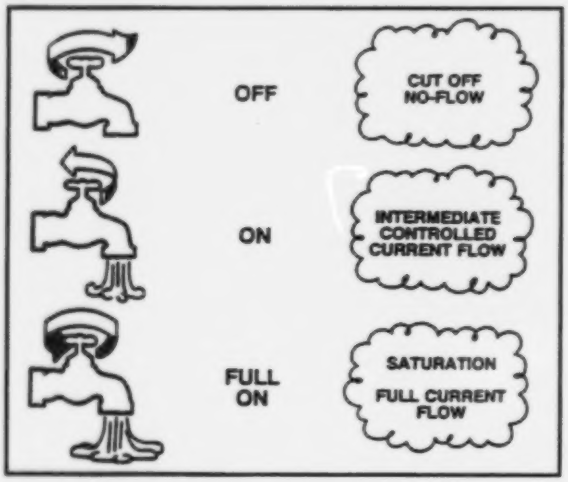

OFF
CUT OFF NO-FLOW
ON
INTERMEDIATE CONTROLLED CURRENT FLOW
FULL ON
SATURATION
FULL CURRENT FLOW

Fig. 9. Increasing the base current increases emitter current until the saturation point is reached. (Courtesy of General Motors Corp.)

When there is no current flow in the base, there is no current flow through the collector emitter junctions. As the current into the base is increased, the emitter current increases also until a maximum is reached. This maximum is called *saturation*, as shown in figure 9. Increasing the base current past this point will not increase the emitter current.

Note: when we are talking about the various current flows in a transistor, it is normal to discuss the current that flows through the collector and emitter leads as simply the emitter current. Since the current flowing through the collector is from 25 to over a 100 times greater then the base current and both the collector and base current are combined to form the emitter current, we often ignore the base current in our calculations.

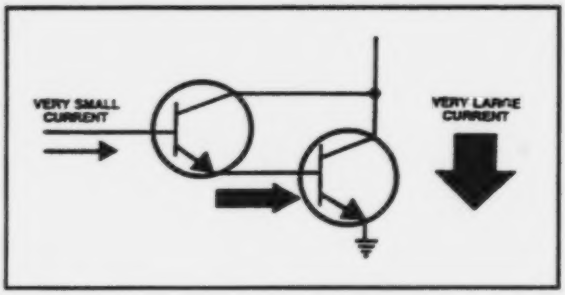


Fig. 10. A Darlington Pair allows a very small current to control a very large current. (Courtesy of General Motors Corp.)

Notice, in figure 10, how a small amount of current in the first transistor will result in emitter current from the first transistor which will supply the base current for the second transistor. This arrangement of two transistors is called a Darlington Pair. The first transistor is often a low current transistor with a high beta, and the second transistor is a high current transistor with a low beta. This circuit results in a beta or current gain that is equal to the beta of each of the transistors multiplied. For example, if transistor one has a beta of 100 and transistor two has a beta of 25, then the total beta for the circuit is 100 times 25 or 2,500. This means that the 10 amp can be controlled by 10 ÷ 2,500 or 4 mA of current.

A transistor that is capable of handling as much current as 10 amp would typically have a beta or current gain of 25. This means that the base would have 0.4 A of current (10 A ÷ 25). This 0.4 A of current is still a lot of current for control purposes. Figure 11 shows how two transistors are often used to increase the beta and reduce the amount of base current that is required to control a large emitter current.

Transistor Operation

For most automotive applications, the transistor is used as a switch. This means that a small amount of current is used to turn the transistor full on or into saturation, as shown in figure 10, or to turn the transistor completely off. Two basic types of circuits are used for transistor switches. The first transistor switch is used to simply ground the circuit that is being controlled, and the second type controls the amount of current used by the controlled circuit. The circuit in figure 11 shows the simpler type of switch, which simply grounds the controlled circuit.

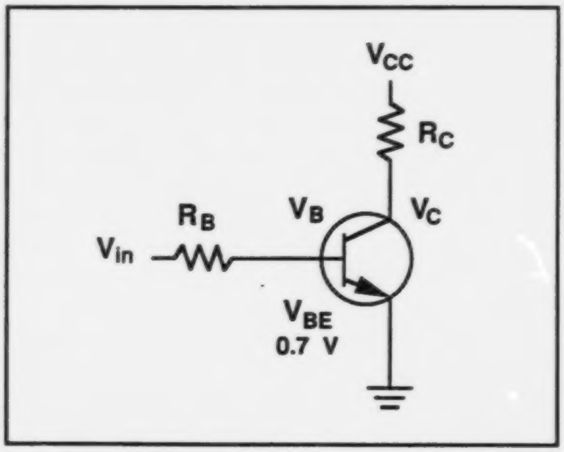


Fig. 11. A switching transistor circuit

In figure 11, the controlled circuit is represented by the resistor R_C. The resistor R_B limits the current to avoid damaging the base emitter junction. V_{cc} stands for the supply voltage, which in most automotive applications is 12 volts.

Most transistors used in switching circuits in automotive applications will have a beta or current gain greater than 10. Using a beta of 10 to calculate the base current will keep the base emitter current low enough to avoid burning up the base emitter junction. In our example, if the expected collector current is 500 mA, then the base current should be 1/10 of that, or 50 mA, based on our assumed beta of 10.

Remember that the voltage from the base to the emitter is always 0.7 volt for a working transistor. If the voltage "V_{in}" is equal to 6 volts, then the voltage across the resistor R_B is 6 volts minus the 0.7 volt that is across the base emitter junction. This leaves 5.3 volts across the resistor R_B. This voltage of 5.3 volts divided by the base current of 50 mA through the resistor R_B will give the value of the resistor. The resistor value is 106 ohms, or rounded to 100 ohms.

For our example, the resistor of 100 ohms in the base circuit of the transistor will limit the current, protecting the transistor, and also cause the transistor to go into saturation. When the transistor goes into saturation, it effectively grounds the resistor R_C where it is connected to the transistor.

Figure 12 shows another way to use a transistor as a switch. In this circuit, the current through the resistor R_C is a function of the base voltage (V_{BB}). This means that the current through R_C will only change if the base voltage changes. The voltage supplying the circuit (V_{CC}) will have no effect on the current through resistor R_C.

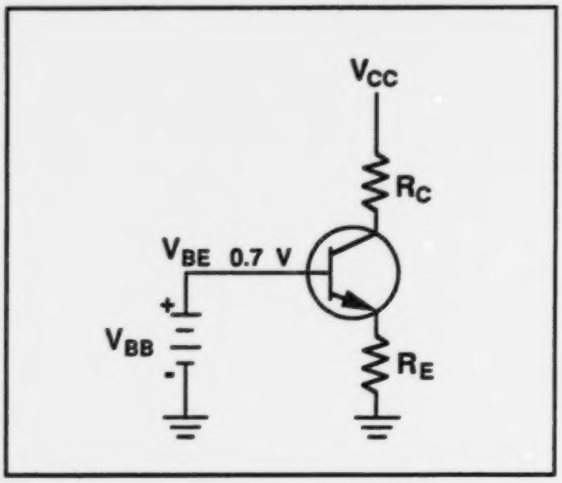


Fig. 12. A second way of using a transistor as a switch

If you assume that V_{BB} is 6 volts and R_E is 1 kΩ, then you can calculate the amount of current that will pass through the collector resistor R_C. First notice that with V_{BB} equal to 6 volts, there are 6 volts from the base to ground. The base emitter junction has 0.7 volt across it which, when subtracted from the 6 volts, leaves 5.3 volts across the 1 kΩ emitter resistor. Ohm's law can then be used to find the current through the emitter resistor which is $5.3 \div 1000$, or 5.3 mA of current. Nowhere in our calculations for the emitter current did we consider the voltage applied to the collector.

To calculate the required value for the emitter resistor when using this circuit, you must find the expected voltage that will be across the emitter resistor R_E and divide that by the required current. The voltage that will be across the emitter resistor is equal to the input signal voltage minus the 0.7

volt across the base emitter junction. The current required by the load in the collector or R_C is the current that will pass through the emitter resistor. Remember that the added base current is too small an addition to consider in our calculations.

This second circuit is an excellent circuit for controlling the current through light-emitting diodes which are sensitive to changes in current. They will change their brightness with variations in current.

Self-Test

Answers will be at the end of the assignment.

1. In the circuit in figure 11, what should the base resistor be if the load (R_C) needs 300 mA and the signal voltage into the base is 5 volts?
2. If we use the circuit in figure 12 for problem 1, what should the value of R_E, the emitter resistor, be?

The Unipolar Transistor

The bipolar transistor that you have been studying is a current-controlled device. This means that the emitter current is controlled by base current and not base voltage. The unipolar transistor is a voltage-controlled device. Instead of a base, the control input is called a gate, and the voltage on the gate controls the amount of current that passes through the transistor.

Most of the computer circuitry in automotive applications will have integrated circuits made from unipolar transistors. Very few individual transistors, either bipolar or unipolar, are used in automotive circuits.

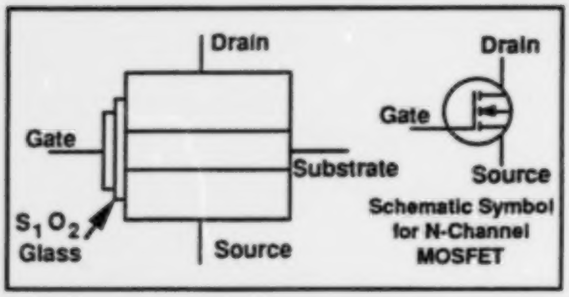


Fig. 13. MOSFET transistor for N-channel enhancement-type

Figure 13 shows the most common unipolar transistor, called a MOSFET (metal oxide semiconductor, field-effect transistor). The voltage on the gate is used to control the current through the transistor. Notice that there is no electrical connection between the gate and the rest of the transistor. A deposit of SiO_2 or glass is placed between the metal connected to the gate lead and the rest of the transistor. This means that there is no steady current flow in the gate of a MOSFET transistor.

When a voltage is applied to the gate of the MOSFET, the static charge from this voltage blocks the flow of current in the transistor. If the voltage is too high, it may arc through the glass insulator between the gate and the semiconductor material. When the glass is broken from a voltage arc, the device is destroyed. A high voltage can be placed on the gate from ordinary static electricity. This is the reason why precautions must be taken when handling integrated circuits. It is best to avoid touching the leads on an integrated circuit and to always store it in its conductive packaging.

Integrated Circuits

An integrated circuit is a transistor circuit formed on one piece of semiconductor and enclosed in a plastic pack age. The most common type (DIP, for dual inline parallel) will have the leads coming out on each side of the plastic package. The simple comparator is one of the more basic integrated circuits and is often incorporated into a more complex circuit.

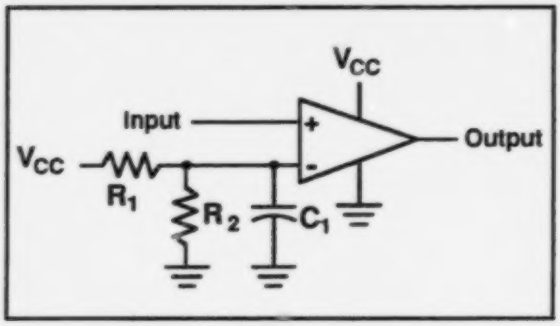


Fig. 14. Comparator circuit

The circuit in figure 14 shows a triangle connected to two resistors and a capacitor. The triangle represents an integrated circuit, and the triangle shape represents an amplifier. In this circuit, the triangle is a comparator that has two inputs and one output. There are also connections for power and ground, shown as V_{CC} and the ground symbol.

The comparator compares the voltage on each of its inputs and directs the output to go either high or low depending on the two inputs. When the output goes high, it will go to 12 volts if the input voltage at V_{CC} is 12 volts. It will go to zero when the connection shown as ground is grounded. Sometimes this circuit is used with a positive and negative supply. The negative supply is then connected to the point shown as ground in the schematic. When the output goes low with a negative supply, the output will go to the voltage value of that negative supply.

Notice the plus and minus signs before each of the inputs to the comparator (fig. 14). If the voltage on the plus input is higher than the voltage on the minus input, the output will go high. When the voltage on the minus input is higher than the voltage on the plus input, the output will go low.

The circuit in figure 14 shows the voltage fixed on the minus input as a result of the two resistors. If V_{CC} is 12 volts and the two resistors are equal in value, then the voltage on the minus input will be 6 volts. As the input voltage to the plus input goes from a value below 6 volts to a value above 6 volts, the output will switch from 0 volts to 12 volts as the plus input crosses the 6-volt threshold. The capacitor on the minus input is used to stabilize the circuit.

This type of circuit is used to monitor the variable voltage from a sensor and switch its output when the sensor voltage reaches the appropriate value. The output of this circuit is often connected to one of the onboard computers in the automobile.

Self-Test Answers

1. *To calculate the base resistor, first find the voltage drop across the resistor. The voltage drop across the base resistor is the 6 volts from the signal minus the 0.7 volt across the base emitter junction, or 5.3 volts. Next, take 10% of the 300 mA for the current through this resistor. Now, Ohm's law will give 143 Ω for the resistor in the base circuit of the transistor.*

2. *For this problem, we again have a load that requires 300 mA of current*

and a 6-volt signal. The full 300 mA of current goes through the emitter resistor. You have to find the voltage drop across it before you can use Ohm's law to find the value of the resistor. The voltage across the resistor will be the 6-volt signal voltage minus the 0.7-volt drop across the base emitter junction. This gives 5.3 volts across the emitter resistor, with 300 mA of current going through it. Ohm's law tells you the value of the resistor is 17.7 Ω, rounded to 18 Ω

Summary

The bipolar transistor is made using three pieces of semiconductor material. The NPN transistor is made using P-type material sandwiched between N-type material. The PNP is reversed, sandwiching N-type material between two pieces of P-type material. The primary difference is the polarity of the current through the transistor.

The current through the bipolar transistor is controlled by the amount of current through the base emitter junction. The ratio of collector current to base current is called the current gain of the transistor or the beta of the transistor.

In automotive applications, the transistor is primarily used as a switch. There are two common methods of using the transistor as a switch. The first method is to put a resistor in series with the base to limit the current into the base emitter junction. It is necessary to limit the current into the base emitter junction to avoid destroying the transistor.

The value of this base resistor can be calculated by first determining the voltage drop across it and then dividing that by the current through it. The base current through this base resistor will be 10% of the expected collector current.

The other circuit for a transistor switch has the advantage of holding the current constant through the collector circuit as long as the signal voltage into the base remains constant. This circuit does not have a resistor in the base circuit. The resistor is in the emitter circuit. The emitter resistor value can also be calculated by dividing the voltage drop across this resistor by the current through it.

The unipolar transistor, which is more common in integrated circuits, is a voltage-controlled transistor. The amount of voltage on the gate controls the current through the device. A problem with this type of transistor is that too much voltage on the gate will destroy the transistor. It is easy to get too much voltage on the gate from static electricity on a technician's hands or static buildup from friction. To avoid destroying the transistor, the unipolar transistors that are sensitive to this problem are stored in conductive packages, and precautions are taken to ground any person who may have to handle them.

The comparator is an integrated circuit amplifier that is used to compare the signals on its inputs and switch its output based on the voltage level of the inputs. Each input is labeled either positive or negative. If the voltage is higher on the positive input, the output will go high or have the same voltage on it as the voltage used to supply the device. If the voltage on the minus input is higher, the output will go low or to ground if the device is grounded. The comparator or a similar circuit is often used to supply the status of a sensor to the onboard computer in an automobile.

Exercise

1. Does the current flow in or out of the base of an NPN transistor (conventional current flow)?

2. If a transistor has a beta of 200, how much current will be flowing through the collector with 0.5 mA of current flow through the base?

3. If one transistor in a Darlington Pair has a beta of 150 and the other transistor has a beta of 30, what is the total current gain for the pair?

4. What value resistance should be put in the base circuit to protect the base emitter junction of a transistor that will be switching 500 mA with a signal input of 5 volts?

5. What should the emitter resistance be for a switching transistor that will be controlling an LED that requires 15 mA? The signal input to the base will be 7 volts.

6. How much current flows through the gate of a MOSFET transistor when it is controlling 100 mA of current?

7. If a comparator is connected to the 12-volt supply in an automobile and has a fixed 4 volts on the plus input, what will the output voltage be with 3.6 volts on the minus input?

8. If a transistor has 6 volts on the base and a 1 kΩ resistor in the emitter, how much current will be flowing in the collector if the transistor is supplied by 12 volts?

C-8 Transistors

Laboratory Experiment

Essential Elements: **(gg) (1-3)**

Objective

In this experiment, the student will examine the properties of a comparator.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 capacitor
2 resistors; both the same value and between 2 and 50 kΩ
1 1 kΩ resistor
1 comparator
1 socket for the comparator
1 DVOM

Procedure

The capacitor can be any size over 1 mF. Redraw figure 1 on a separate piece of paper or your notebook. Pick out the two resistors that are needed for the circuit, and show their values on your drawing. Add the 1 kΩ resistor to the output for a load. Connect this resistor from the output of the comparator to ground.

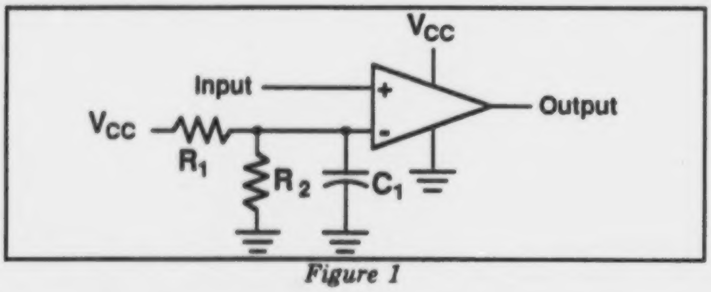


Figure 1

1. Build the circuit in figure 1.

2. Connect the plus input to 12 volts, and use your DVOM to measure the voltages on the two inputs and the output. Record these values in your notes.

3. Switch the plus input to ground, and measure and record the output voltage.

   The output voltage should have gone to zero when the plus input was connected to ground.

4. Change the circuit so the two resistors are on the plus input to the comparator. Do parts 2 and 3 over again, using the minus input instead of the plus input. Record the differences in output voltages in your notes.

   With the inputs reversed, the output voltage should be the opposite of the voltages you first recorded from parts 2 and 3.

C-9

Computer Circuits

Essential Elements: (gg)(1-3)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *electricity*
- *magnetism*
- *digital multimeter*
- *electronic components*
- *automotive schematics*
- *wire and connector repair*

Specific Objectives:

After completing this assignment, you will be able to:

- *convert from the binary numbering system to hexadecimal*
- *determine the output of a logic gate with various inputs*
- *demonstrate a knowledge of flip-flops and simple memory devices*

Digital/Analog Circuits

The typical automobile has many digital circuits and analog circuits. An analog circuit changes in a smooth transition and in proportion to the input signal. The typical gas gauge has a meter that moves smoothly up and down the scale according to the level of gasoline.

A digital signal moves in jumps and not necessarily in proportion to the input signal. If the gasoline gauge were changed to a digital system that read the amount of gasoline in increments of a tenth of a gallon, the readout would jump when the level of gasoline changed a tenth of a gallon. Any changes in the level of gasoline within the tenth of a gallon would show no change on the gauge.

The transistor switch you studied in Assignment C-8 can be used as a digital circuit, and the comparator is normally used as part of a digital circuit. Most digital circuits are built using integrated circuits. The standard voltage for computer or digital circuitry is 0 and 5 volts. The standard voltage for an automobile is 12 volts. If you apply 12 volts to a digital control circuit designed for 5 volts, it will probably damage the circuit.

Computer Numbering Systems

All digital or computer circuitry involves just two states, either *on* or *off*.

When a computer reads the temperature of the engine, it will read it as a series of on and off pulses. The computer does all of its computations using millions of switches that have only two states, either on or off.

Because the computer deals with only two states, it must use a numbering system with only two states. Our conventional numbering system of 0 through 9 has ten different numbers. The number zero is a number and is included to get a total of ten numbers. We call our conventional numbering system the *decimal system*. It has a base of 10 for the ten numbers.

The computer uses a numbering system called a *binary system*, and its base is two. The binary system has only two numbers, 0 and 1. If we start counting in binary, we will start with 0 which is 0 in the decimal system. Next we have 1, which is also 1 in decimal. The number 1 is as high as the binary system will go with only one digit.

In the decimal system, when we reach the number 9, the next number goes back to the beginning with 0, and a 1 is put in front of it. This continues on until the number 19, when the number in front is changed to a 2 and the number to the right starts over with a 0.

The binary system does the same thing, only it doesn't go to the number 9, only the number 1. The next number after 1 in binary is 10. To avoid confusion, we can show the base of a number next to it. The binary number 10_2 with the subscript 2 shows this number is to the base 2 or a binary number. The following is a list of some binary numbers and their decimal equivalents.

Decimal	**Binary**
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

The binary system is difficult for people to work with, and converting from decimal to binary is also cumbersome. The *hexadecimal system* is often used to make it easier for people to work with a computer. The hexadecimal system has 16 numbers or six more than our decimal system. The last six numbers in the hexadecimal system are the letters A through F.

When we count in hexadecimal, we don't stop at 9 and start over with the number 10. Since there are six more numbers in the hexadecimal system, we continue with these additional numbers before going to 10 and starting over. Study the following hexadecimal system and its decimal equivalents.

Decimal	Hex
1	1
2	2
3	3
8	8
9	9
10	A
11	B
12	C
13	D
14	E
15	F
16	10
17	11
24	18
25	19
26	1A
27	1B
28	1C
29	1D
30	1E
31	1F
32	20
33	21

The advantage of the hexadecimal over the decimal is the ease with which it can be changed to binary. The single-digit hexadecimal numbers will all convert to four-digit binary numbers. Many of the computers in automobiles will use word sizes that are four or eight binary digits long. This makes it easy to examine a word in a computer as a hexadecimal number instead of a binary number and still be able to easily convert back and forth from binary to hexadecimal.

We usually use the term *bits* instead of digits when we are talking about word sizes. A bit is one digit, and a *byte* is eight digits. A *nibble* is four bits. The term nibble is not often used since most business computers have word sizes larger than four bits. The automobile may still have four-bit word sizes in many of its systems.

Converting from hexadecimal to binary is a relatively easy process. Many technicians will have the binary equivalent for a single-bit hexadecimal number memorized. To convert a larger hexadecimal number, simply convert each hexadecimal digit to a four-bit binary number. Put the binary numbers in sequence, and the conversion is complete. To reverse the process, separate the binary number into four-bit sections, adding zeros on the most significant bit end if necessary, and convert directly to hexadecimal.

The hexadecimal number $A5_{16}$ converts to 1010_2 for the digit A_{16} and 0101_2 for the digit 5_{16}. Putting the two binary numbers together gives us 10100101_2. The binary number 111110_2 can be changed to hexadecimal by first separating it into two groups of four bits. Two extra zeroes have to be added to the number to get eight bits that will break into two groups of four bits. We add the two zeroes on the most significant bit end of the number. Now the number 00111110_2 can be broken into $0011\ 1110_2$. This converts to 3_{16} for the 0011_2 and E_{16} for the 1110_2 or $3E_{16}$.

Self-Test

The answers are at the end of the assignment.

1. Convert the following hexadecimal numbers to binary:
   $A3_{16}$, FB_{16}, 37_{16}, $D0_{16}$, $9B_{16}$
2. Convert the following binary numbers to hexadecimal:
   11001010_2, 100100_2, 1111101_2

Logic Gates

The computer circuits or digital circuits are made from small circuits that will have a certain output when a particular combination of inputs is present. We call these circuits *logic gates*, and they are represented by logic diagrams.

The logic voltages that make up the input and output signals are all either close to 5 volts or close to 0 volts. We call these inputs and outputs *logic high* or *logic low* for the 5 volts or 0 volts. We can also use the term *1* for 5 volts and *0* for 0 volts. The signal voltages in digital circuits are all either high or low. There are no voltages between or outside of these two voltages or logic states. A voltage of 2.5 volts on a logic gate input would not be a valid input and would represent a failure somewhere in the system.

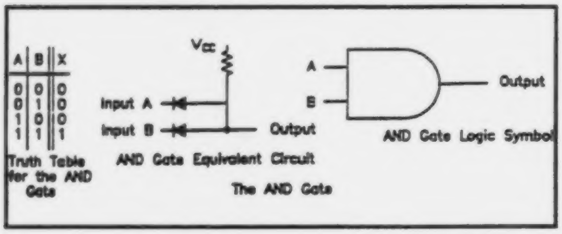

A B X
0 0 0
0 1 0
1 0 0
1 1 1
Truth Table for the AND Gate
Vcc
Input A
Input B
Output
AND Gate Equivalent Circuit
The AND Gate
A
B
Output
AND Gate Logic Symbol

Fig. 1. The AND gate

There are three basic logic gates that all other gates are built from: the AND gate, the OR gate, and the NOT gate.

The AND gate (fig. 1) represents the multiplication function. Notice the truth table, which shows the output with all possible inputs for a two-input gate. The AND and OR gates can have from two to any number of inputs. They will always have at least two inputs. The NOT gate has only one input.

Notice that if the AND gate has a low on any or all inputs, the output will be low. This is the same as multiplying with zero, which will always give a zero for the result. The equivalent circuit is shown to illustrate how an AND gate could be constructed. This is not how they actually are constructed.

Figure 2 shows the OR gate. This gate represents the addition function. The truth table, which shows all possible inputs for a two-input OR gate, shows that the output goes high if there is a high on the input. This is not true addition since 1 + 1 would normally equal 2 or 10_2, instead of 1_2.

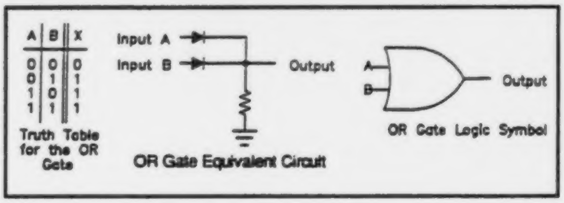

A B X
0 0 0
0 1 1
1 0 1
1 1 1
Truth Table for the OR Gate
Input A
Input B
Output
OR Gate Equivalent Circuit
A
B
Output
OR Gate Logic Symbol

Fig. 2. The OR gate

When you examine the equivalent circuit, remember that the diode symbols show that current can only go in the direction of the arrow when passing through the diode. If there are 5 volts on either one or both of the diode inputs shown in the equivalent circuit, there will be 5 volts on the output.

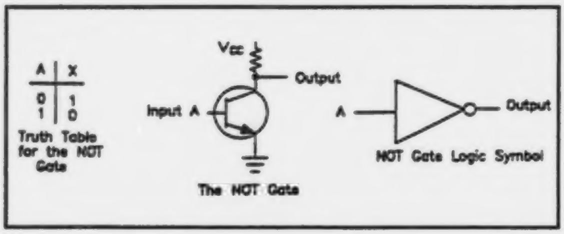
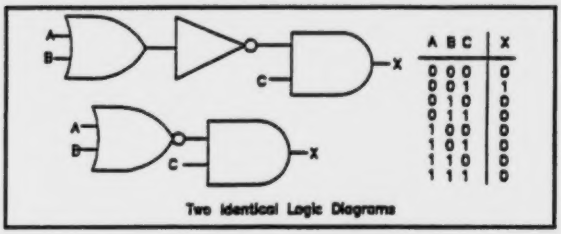

A X
0 1
1 0
Truth Table for the NOT Gate
Vcc
Output
Input A
The NOT Gate
A
Output
NOT Gate Logic Symbol

Fig. 3. The NOT gate

The NOT gate is a very simple gate (fig. 3). It has only one input; whatever is on the input, the opposite is on the output. The NOT gate is often shown as simply a small circle, called a *bubble*, on the input or output of another gate. This bubble inverts the logic that would normally come from this input or output.



A B C	X
0 0 0	0
0 0 1	1
0 1 0	0
0 1 1	0
1 0 0	0
1 0 1	0
1 1 0	0
1 1 1	0

Fig. 4. The identical logic diagram

The logic diagrams in figure 4 show how a bubble is used to show that the logic is inverted. The top drawing uses the complete NOT symbol, and the bottom uses only the bubble on the output of the OR gate. Both of these drawings have the same logic.

When we put a bubble on the end of an OR gate or an AND gate, we change the name of the gate. The OR gate with a bubble on its output is called a NOR gate, and the AND gate with a bubble on its output is called a NAND gate. Putting bubbles on the inputs to a gate does not change its name (fig. 5).

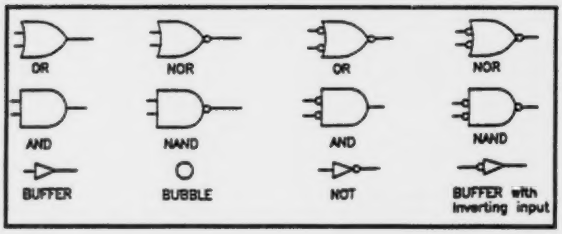


Fig. 5. Logic gate symbols

The triangle, when it stands alone, is simply a buffer or an amplifier. Remember that we used a triangle for the comparator in a previous lesson. In a computer circuit, a buffer would be used to connect a circuit that is switching from 0 to 12 volts to the digital circuit that requires 0 and 5 volts. There would be no change in the logic, but a necessary change in voltage levels.

Although we talk about the logic on the inputs and outputs of these logic gates as high and low or 1 and 0, the actual voltage levels there are usually switching rapidly, and an oscilloscope will appear as pulse waveforms. Figure 6 shows how the waveforms would appear.

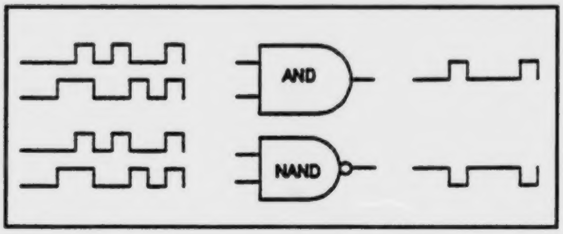
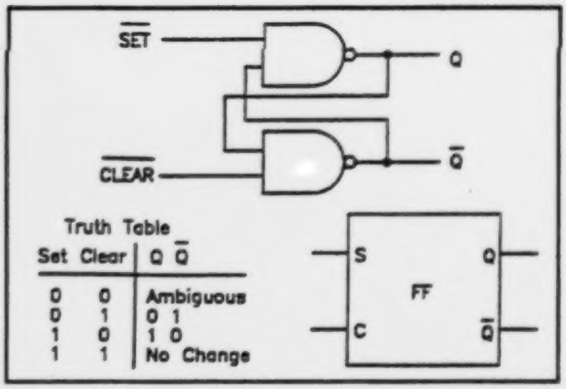


Fig. 6. AND and NAND gates with symbols

The output on the logic gates will change depending on the input at any instant in time. If you mentally draw a vertical line through the input waveforms at points where they change, you can see what the logic is on the input at that time. This will help you to determine what the logic should be on the output for that input.

Flip-Flops

An important function of digital and computer circuits is the ability to hold data or store it for either a brief moment or in memory for a longer period of time. The flip-flop is used for temporary storage of data and is usually arranged to form registers. Figure 7 shows a simple flip-flop using two NAND gates.



Truth Table

Set	Clear	Q $\overline{Q}$
0	0	Ambiguous
0	1	0 1
1	0	1 0
1	1	No Change

Fig. 7. NAND gate flip-flop with active low inputs

The two inputs to this circuit are labeled SET and CLEAR. The lines drawn above the labels indicate that the inputs are "active low." Look at the truth table, and notice that for the Q output to change, one of the inputs has to go low. When both inputs are high, there is no change, and the circuit is in its normal resting state.

The advantage of this circuit is its ability to hold either a high or a low on its Q or inverted Q output during its resting state. By putting a low on the appropriate input, the logic on the output can be changed, and this logic will remain there until another low is placed on the appropriate input or the power is removed from the circuit.

The flip-flop is used to temporarily store data that is sent from a sensor to the computer, when the computer is not ready to process it. Variations of the flip-flop are used for numerous memory systems within the computer system.

Memory Circuits

The basic flip-flop has a volatile memory, which means that it loses its memory when the power to it is turned off. It is normally used in a memory circuit that allows the computer to put data in and take data out of it. Putting data in is called "writing" to it, and taking data out is "reading" data from it.

The memory used by the computers on board an automobile can be separated into two divisions, either ROM or RAM. The RAM memory stands for *random access memory*, but it is usually volatile, read-write memory of the type that would use flip-flops.

The ROM memory is *read only memory* and is normally programmed once at the factory or in a special test setup and is then just read by the computer. Some automobile manufacturers may have different ROMs for their computers that control the fuel injection. A different set of instructions for the computer will improve the automobile's performance under severe conditions like higher altitudes and hot or very cold conditions.

The PROM is a *programmable read only memory* and is a memory system that can be changed. Usually, changing the data in memory requires that the memory chip be removed from the circuit and placed in a fixture that is connected to a computer. The new data can then be written into the chip. Once the chip is installed in the computer on board the automobile, it will operate the same as any other ROM memory chip.

The primary control chip in a computer is the *microprocessor* (fig. 8). This chip holds all the circuitry for processing the data and the control circuitry for reading and writing to the memory chips.

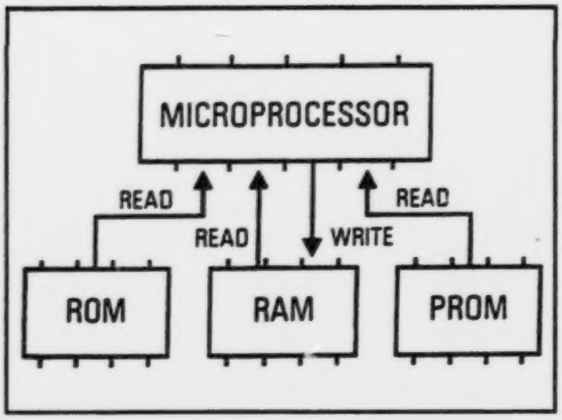

MICROPROCESSOR
READ
READ
WRITE
READ
ROM
RAM
PROM

Fig. 8. Microprocessors and memories

The PROM and ROM are both nonvolatile memories. A nonvolatile memory will not lose any data when the power is removed from the chip. The RAM memory chip will normally lose all of its data when power is removed.

Microprocessor

The onboard computers in an automobile are composed of a microprocessor, memory, clock, and input/output ports. The microprocessor controls the computer, and the clock is used to time the length of pulses and keep everything in sequence. The input/output ports are the connections to the sensors that provide the input data, and the connections to the control motors or display devices controlled by the computer.

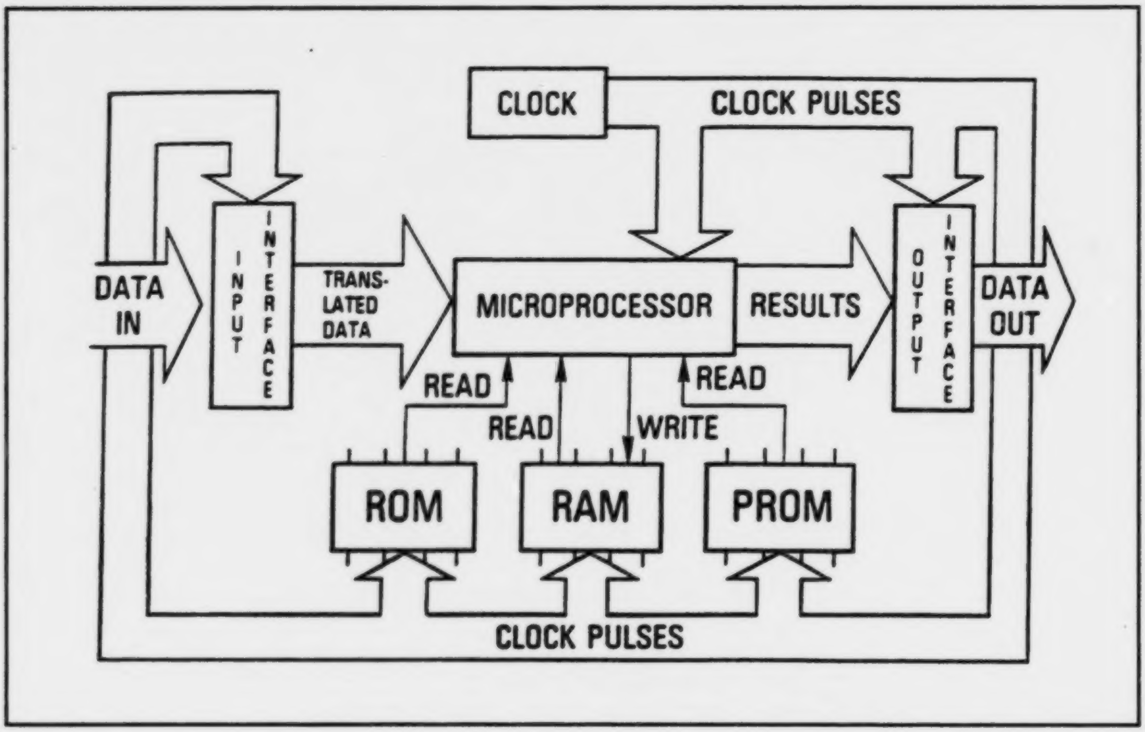

CLOCK
CLOCK PULSES
DATA IN
INPUT INTERFACE
TRANS-LATED DATA
MICROPROCESSOR
RESULTS
OUTPUT INTERFACE
DATA OUT
READ
READ
WRITE
READ
ROM
RAM
PROM
CLOCK PULSES

Fig. 9. Input and output interfaces (Courtesy of General Motors Corp.)

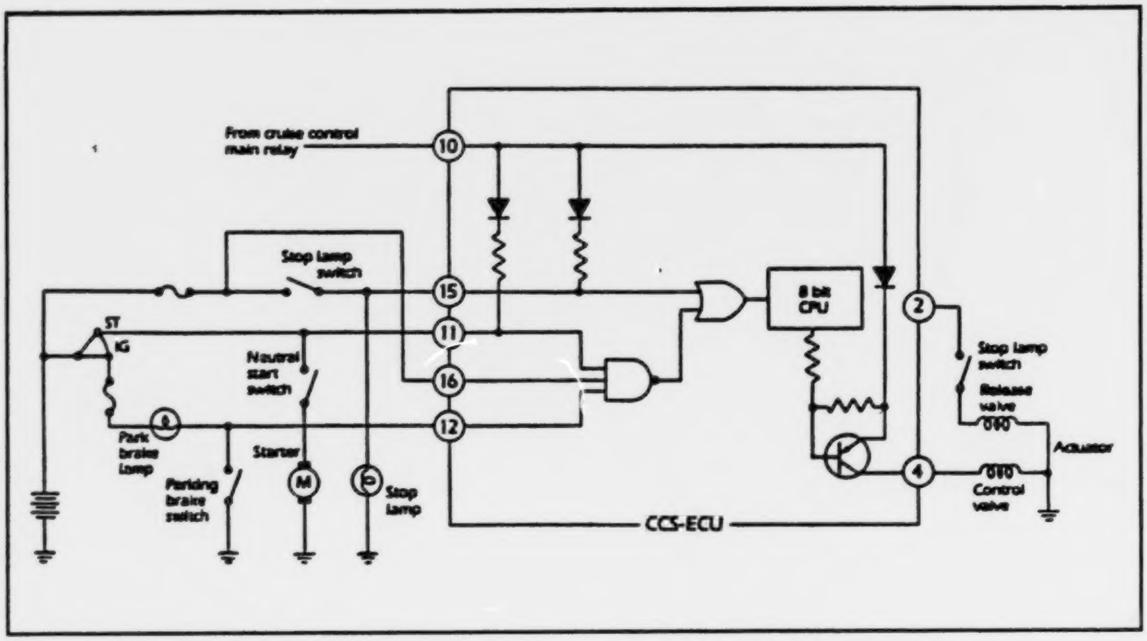

From cruise control main relay
10
Stop lamp switch
15
ST
IG
11
Neutral start switch
16
12
Park brake lamp
Parking brake switch
Starter
M
Stop lamp
8 bit CPU
2
Stop lamp switch
Release valve
Actuator
4
Control valve
CCS-ECU

Fig. 10. Cruise control circuitry (Courtesy of Toyota)

Figure 9 shows the basic parts of the inside of a computer. The interface on the input and output ports are buffers to protect the computer from the outside world and to provide temporary storage so the data will move smoothly in and out of the computer.

Self-Test Answers

1. 10100011_2, 11111011_2, 00110111_2, 11010000_2, 10011011_2
2. CA_{16}, 24_{16}, $7D_{16}$

Exercise

1. Convert the following hexadecimal numbers to binary: $C7_{16}$, $2A_{16}$, 97_{16}, EF_{16}, $1C_{16}$
2. Convert the following binary numbers to hexadecimal: 00101110_2, 1111001_2, 111101_2
3. Give the output on each of the four logic gates, in figure 10, with the following inputs:

   a. A 0, B 1, C 1, D 1, E 1
   b. A 1, B 0, C 0, D 1, E 1

4. Use the following truth table to find the inputs that will show a different output between a two-input NAND gate and an OR gate with bubbles on both of its two inputs.

A	B	X
0	0	?
0	1	?
1	0	?
1	1	?

C-9 Computer Circuits

Workbook

Essential Elements: (gg) (1-3)

Objective

In this workbook, the student will examine the logic gates and computer mathematics.

Procedure

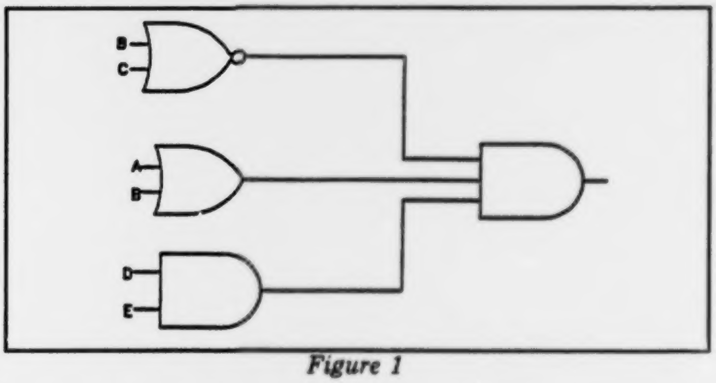


Figure 1

Figure 1 shows a cruise control system for a Toyota. The box labeled "8 bit CPU" is the computer. When the output of the OR gate is low, the CPU will feed a variable amount of current to the transistor operating the control valve. When the output of the OR gate is high, the CPU turns off the control valve.

1. Examine figure 1, and determine what logic levels should be on inputs 15, 11, 16, and 12. Record these logic levels in your notes.

2. Notice that the stop lamp is connected between the stop lamp switch and a resistor diode combination feeding current from the main relay. If the stop lamp burns out, what effect will this have on the cruise control system? Write your answer in your notes.

3. Describe what happens to the cruise control system when the parking brake switch is closed. Write your answer in your notes.

Unit

D

Engine Electrical Systems

D-1 The Battery
D-2 The Charging System
D-3 The Cranking System

D-1

The Battery

Essential Elements: (gg)(1-4)

Unit Objectives:

After completing this instructional unit, you will be able to explain the functions of:

- *automotive batteries*
- *charging systems*
- *engine starting systems*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how to test a lead acid car battery*
- *explain how to charge and maintain a lead acid car battery*
- *calculate the internal resistance of a car battery*

Types of Batteries

A battery is made up of cells. A cell is an individual chemical unit that will supply a voltage that is determined by the chemistry of the cell. The lead acid cell supplies a voltage of approximately 2 volts, and the dry cell used in flashlights has a cell voltage of 1.5 volts. The typical car battery has 6 cells wired in series to provide approximately 12 volts.

All batteries can be divided into two basic groups, primary cells and secondary cells. The primary cell cannot be recharged and is designed to be discarded when it is discharged. The ordinary flashlight light battery is an example of a primary cell. The secondary cell can be recharged. The typical car battery is a secondary cell battery (fig. 1).

Lead Acid Car Battery

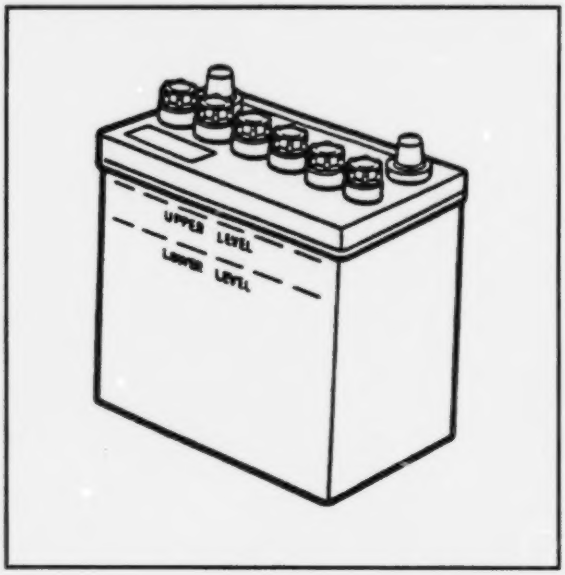


Fig. 1. A typical lead acid battery (Courtesy of Toyota)

The car battery in a typical auto is used to supply current to a variety of accessory items when the engine is not running. The clock and computers are all kept "alive" by the battery when the vehicle is unattended. The primary purpose of the car battery is to start the engine. The lead acid battery intended for automotive use is designed to primarily meet the function of starting the car under all expected conditions.

Lead Acid Battery Construction

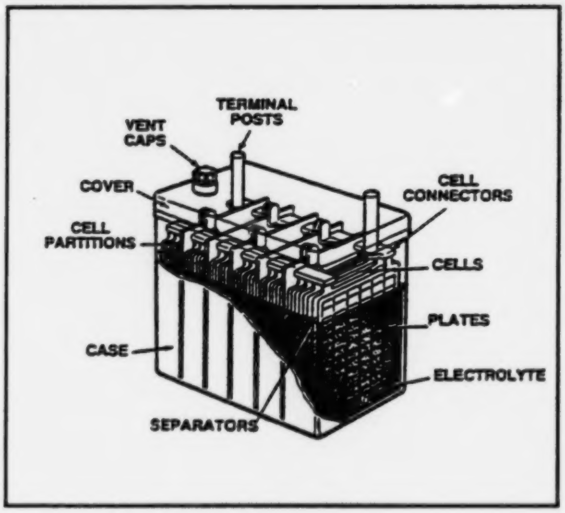


Fig. 2. Battery construction (Courtesy of Toyota)

The car battery (see fig. 2) is a typical low maintenance battery. This battery has a vent cap to release any gas buildup and top-mounted terminal posts.

The case, made of a strong plastic, holds the electrolyte and provides separation between the six cells. There is a space at the bottom of the battery for sediment that comes off the plates. Some batteries of this type will have translucent plastic cases to make it easier to check the fluid level in the battery.

The electricity is generated by the chemical action of the plates and the liquid electrolyte. Each set of plates and electrolyte, which forms a cell, is separated from the other cells or plates and electrolyte. The plates are made of a grid network of antimony and lead alloy. The grid system increases the surface area that is in contact with the electrolyte.

The plates that provide the positive potential have lead peroxide (PbO_2) coating the antimony lead alloy grid. These plates appear brown. The negative plates have a gray sponge lead (Pb) covering. A thin porous insulator, often made from woven glass or plastic, keeps the plates from touching and shorting out. This insulator is porous to allow the electrolyte to easily pass through.

Notice in figure 2 that each cell has a number of plates, and each plate is in parallel with the other plates. Having the plates in parallel increases the current capacity of the cell without changing the voltage. The voltage is fixed, based on the chemistry of the system and will be 2.2 volts for any size or number of plates as long as they are in parallel. The cells are then connected in series, using heavy cast alloy straps inside the battery, to provide the 12-volt output.

The liquid electrolyte is a mixture of sulfuric acid (H_2SO_4) and pure water (H_2O). The chemical reaction between the plates and the electrolyte creates the voltage or electrical pressure. A battery with a full charge will have about 36% acid and 64% water.

Theory

When a battery is supplying current or discharging, there is current flow *from* the positive terminal (conventional current flow). When the battery is being charged, there is current *into* the positive terminal. The current goes in the opposite direction when the battery is being charged. To charge any battery, the charging voltage must be greater than the battery voltage. The higher the voltage is above the battery voltage, the faster the battery charges.

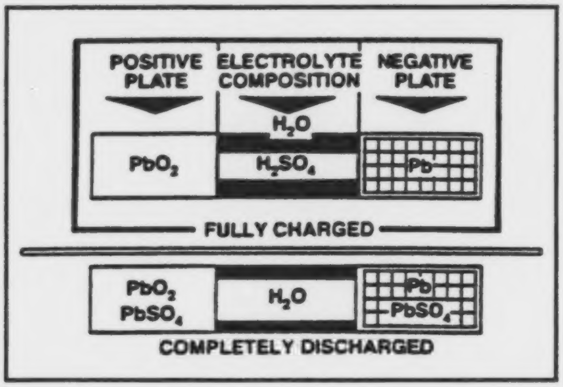


Fig. 3. Chemical changes in batteries during discharge. (Courtesy of General Motors Corp.)

When a lead acid battery is fully charged, the positive plate will be composed of lead oxide (PbO_2), and the negative plate is pure lead (Pb). The electrolyte will be 36% sulfuric acid (H_2SO_4). The process of discharging changes the chemical composition of the materials in the battery until at full discharge the positive plate has both lead oxide and lead sulfate, the negative plate has lead and lead sulfate, and the electrolyte is plain water (see fig. 3).

Figure 4 shows how the chemical changes take place during charging and discharging. When a load is placed across the terminals and the battery is discharging, the oxygen from the lead oxide in the positive terminal combines with the hydrogen in the sulfuric acid to form water. The sulfate ion, which is left when the sulfuric acid loses its hydrogen atoms, goes to both of the terminals and combines with the lead to form lead sulfate. If this process of discharging is allowed to continue, all of the sulfuric acid will be broken down, leaving only water for the electrolyte, as seen in figure 3.

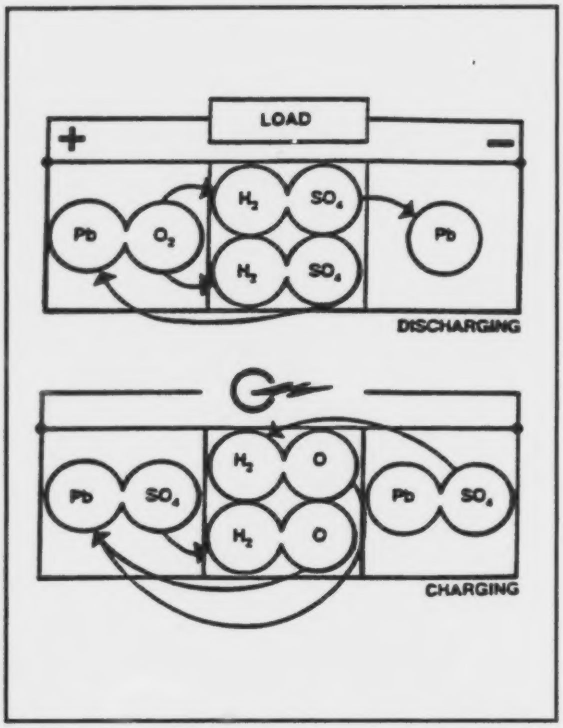


Fig. 4. Chemical changes in batteries during charging. (Courtesy of General Motors Corp.)

The charging process (see fig. 4) causes the sulfate ion that has combined with the lead in the negative terminal to move back into the electrolyte and reform the sulfuric acid. The oxygen that is displaced from the water when it combines with the sulfate to become sulfuric acid now goes to the positive terminal and combines with the lead to form lead oxide, displacing the sulfate ion there. This sulfate ion goes back into the electrolyte to form more sulfuric acid.

Battery Capacity

The car battery's primary purpose is to crank the engine. Different ratings are used to compare batteries and their ability to crank an engine and provide reserve power. The most common ratings are cold cranking amperes (CCA), reserve capacity (RC), amp hours (AH), and power in watts.

A lead acid battery loses some ability to provide current in very cold weather. The CCA rating measures this ability of a battery to provide enough current to start a car in cold weather.

A typical eight-cylinder engine will require over 400 amperes to effectively turn the starter motor and crank the engine. A smaller four-cylinder engine will require somewhat less current. The CCA rating specifies the amount of current the battery can deliver for 30 seconds at 0°F and maintain a battery voltage of 7.2 volts.

The reserve capacity (RC) rating shows how long the battery can supply the current requirements of a car when the charging system has failed. The RC rating is the number of minutes a battery can supply 25 amperes, at room temperature, while maintaining a voltage of at least 10.5 volts.

The amp-hour (AH) rating is used on many different types of batteries. The test that is conducted to determine the AH rating for an automotive battery is done for 20 hours. The number of amperes it can deliver during a 20-hour period at room temperature and with the battery voltage staying above 10.5 volts will be the current part of the specification. This current is then multiplied by the 20 hours to get the AH rating. For example, if a car battery can provide 3 amperes for 20 hours under these test conditions, then it is a 60 amp-hour battery (3 times 20).

The power available from a battery, according to the automotive tests, is equal to the power the battery can deliver at 0°F. Power is determined by multiplying the current times the voltage. If the battery delivers 400 amperes at 10 volts with a temperature of 0°F, then 400 times 10 gives 4,000 watts for the battery.

Table 1 gives some typical numbers for automotive batteries.

BCI Group*	Type (Months)	Plates (No.)	Ratings	
			CCA (amp)	RC (min.)
24, 24F	24	48	350	55
	36	54	400	60
	48	72	525	100
27, 27F	48	84	560	115

*BCI=Battery Council International. An "F" suffix on the group number indicates that the positive (+) battery terminal is on the left when looking at the case top with the terminals closest to you.

Table 1. Replacement Batteries
(Courtesy of Toyota)

Charging Problems

Five factors reduce the ability of the battery to accept a charge: low temperatures, state of charge, plate area, impurities in the electrolyte, and gassing (fig. 5).

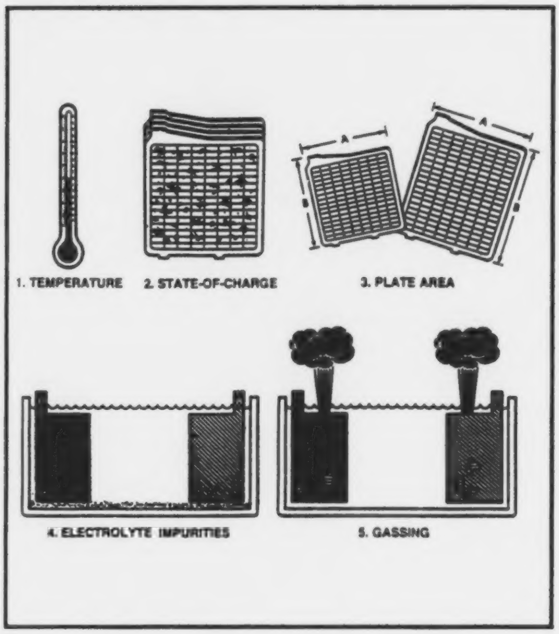

1. TEMPERATURE
2. STATE-OF-CHARGE
3. PLATE AREA
A
B
4. ELECTROLYTE IMPURITIES
5. GASSING

Fig. 5. Five factors that affect charging are temperature, state of charge, plate area, electrolyte impurities, and gassing. (Courtesy of Toyota)

As the temperature drops, a lead acid battery will increase its internal resistance. The electrolyte does not react with the plates as fast when it is cold.

A battery that is severely discharged will not take a rapid charge because of the buildup of hard sulfate crystals on its plates. Charging with a slow trickle charge at the beginning can save a battery that is severely discharged.

Smaller plates will charge faster than large plates because of the difference in area to be charged. Any impurities that get into the electrolyte add extra ions which do not contribute toward a charge. The impurities only add to the internal resistance and make it harder to fully charge the battery.

When a battery is charged rapidly and allowed to become warm, the oxygen and hydrogen that form at the plates will escape as gas. This oxygen and hydrogen are needed in the electrolyte to form the water. Without the water, the ratio of acid to water will be wrong and cause difficulty charging the battery.

Battery Diagnosis and Testing

All batteries need some preventive maintenance. A visual check of the battery case, terminal posts, cables, electrolyte level, and hold-down straps is needed periodically (fig. 6).

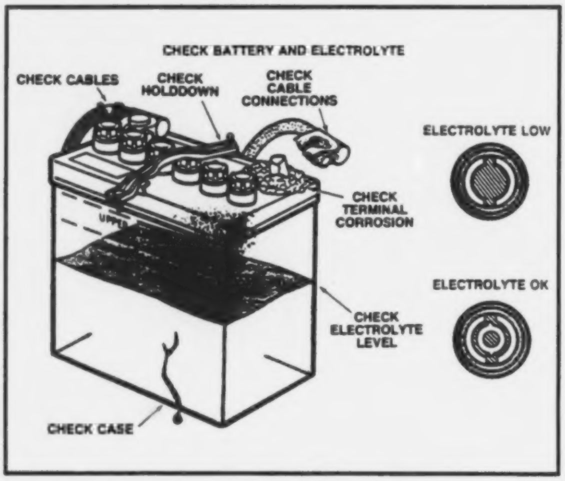

CHECK BATTERY AND ELECTROLYTE
CHECK CABLES
CHECK HOLDDOWN
CHECK CABLE CONNECTIONS
ELECTROLYTE LOW
CHECK TERMINAL CORROSION
UPPER
ELECTROLYTE OK
CHECK ELECTROLYTE LEVEL
CHECK CASE

Fig. 6. Check battery and electrolyte. (Courtesy of Toyota)

The onboard computer memories and other electronics require a small amount of current when the vehicle is idle. This is typically no more 0.2 amp for most cars. If the battery is going dead while the car is parked, then this should be checked. The amount of current needed can be determined by using an ammeter in series with the ground lead off the battery (fig. 7).

Note: You can use a small value resistor instead of the ammeter and measure the voltage drop. Then use Ohm's law to calculate the current flow.

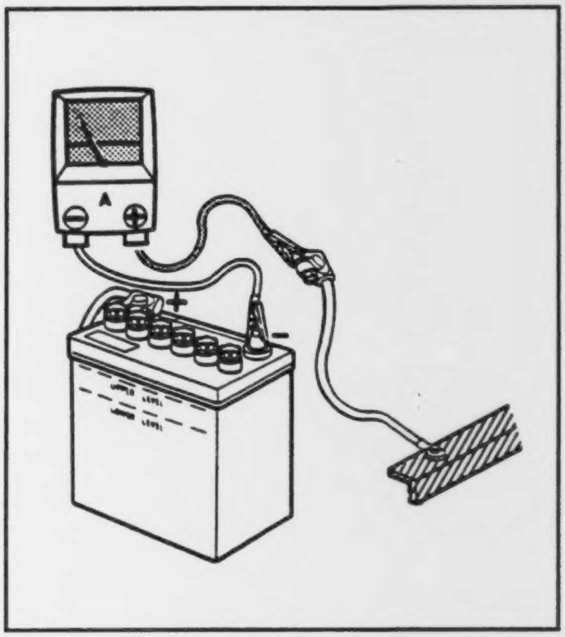


Fig. 7. Check for battery drain with ammeter (negative to ground). (Courtesy of Toyota)

Sometimes there is enough liquid and dirt on the top of a battery to cause electrical leakage from one terminal to another. You can check this with your DVOM by connecting one of your meter's terminals to the negative battery terminal and then checking for any voltage on the plastic top of the battery (fig. 8). If you read a voltage that is higher than 0.5 volt, clean the top of the battery case.

An accurate method of checking the state of charge of a battery is to use a hydrometer to measure the specific gravity of the electrolyte. The specific gravity of a liquid is the weight of the liquid compared with water. The specific gravity of sulfuric acid is 1.835, or it is 1.835 times as heavy as water. When the 36% of acid is added to water, the final specific gravity of the electrolyte is 1.270 (fig. 9).

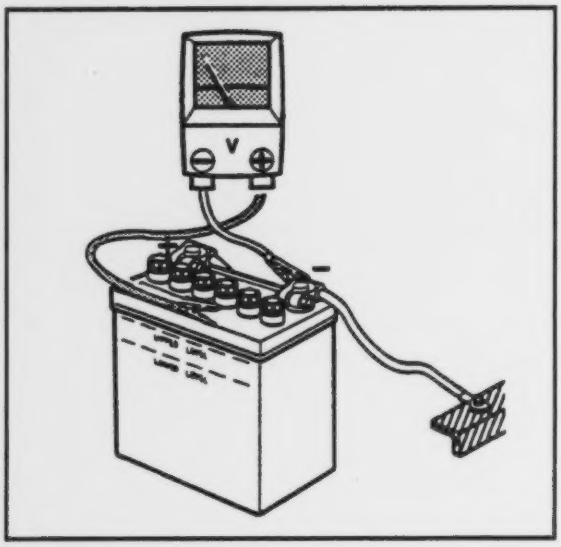


Fig. 8. Check for battery drain with voltmeter (negative to case top). (Courtesy of Toyota)

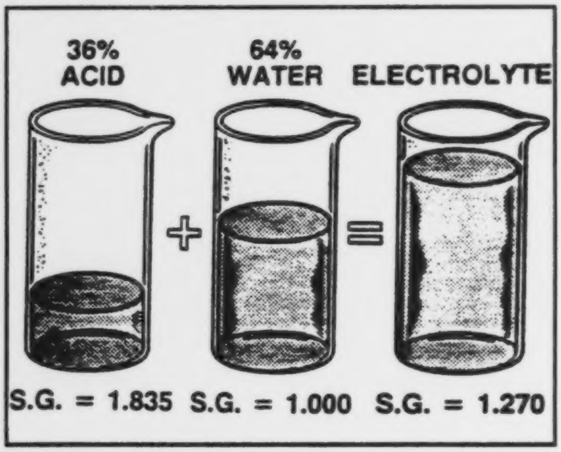


Fig. 9. Electrolyte is composed of water and acid. (Courtesy of Toyota)

You can use the hydrometer to measure the specific gravity of the electrolyte. The specific gravity of the electrolyte tells us what is the ratio of acid to water. Remember that this ratio of acid to water changes with the state of the charge of the battery.

To measure the specific gravity, first remove all of the vent covers on the battery, then insert the hydrometer tube into the liquid electrolyte, starting with the cell closest to the positive terminal. Next, use the bulb to draw some liquid up into the hydrometer. Read the float in the hydrometer (fig. 10).

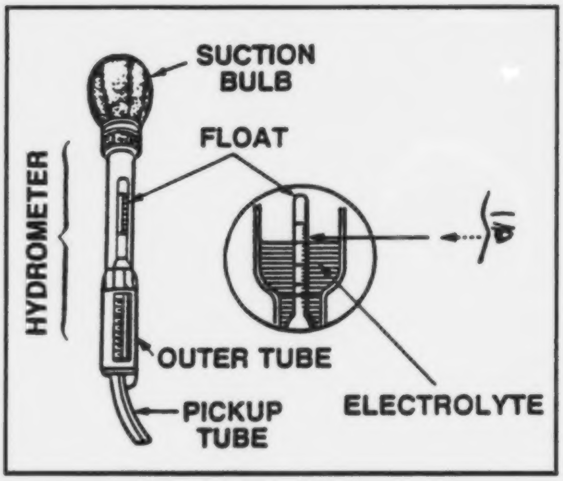
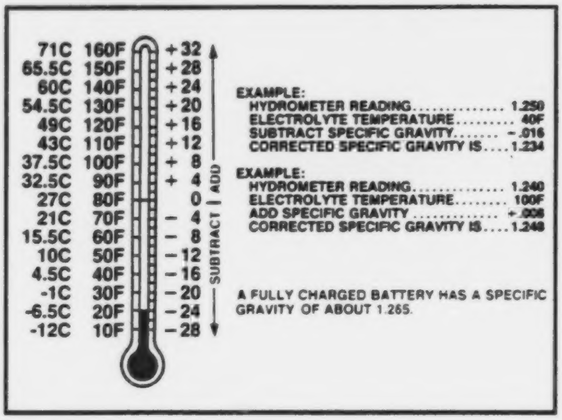


Fig. 10. The hydrometer measures the specific gravity of electrolyte. (Courtesy of Toyota)

For an accurate specific gravity, the temperature of the electrolyte should also be read, and the hydrometer reading corrected for temperature. Most hydrometers will have a thermometer built into the instrument. Figure 10 shows how to add or subtract from the hydrometer reading for different temperatures. Notice that if the electrolyte temperature is between 70° and 90°F, it will have a negligible effect on the readings. Finally, you should record the readings for all six of the battery cells.

The hydrometer test results will tell you a lot about the battery. A fully charged battery will have a specific gravity reading of 1.265, as shown in table 2. Table 2 also shows the state of the charge for other specific gravity readings. If there is a difference between cells of 0.5 specific gravity or more, then the cell that is different has failed, and the battery should be replaced (table 3). A dead battery with a specific gravity reading of 1.120 should be recharged slowly. This battery may not take a charge as a result of the buildup of material on the plates.



EXAMPLE:
HYDROMETER READING.............. 1.250
ELECTROLYTE TEMPERATURE.......... 40F
SUBTRACT SPECIFIC GRAVITY....... −.016
CORRECTED SPECIFIC GRAVITY IS....1.234

EXAMPLE:
HYDROMETER READING.............. 1.240
ELECTROLYTE TEMPERATURE......... 100F
ADD SPECIFIC GRAVITY............ +.008
CORRECTED SPECIFIC GRAVITY IS....1.248

A FULLY CHARGED BATTERY HAS A SPECIFIC GRAVITY OF ABOUT 1.265.

Table 2. Specific gravity changes with temperature. (Courtesy of Toyota)

State of Charge	Specific Gravity	Open-Circuit Voltage
100%	1.265	12.6
75%	1.225	12.4
50%	1.190	12.2
25%	1.155	12.0
DEAD	1.120	11.9

Table 3. Difference between cells should not vary more than 50 points. (Courtesy of Toyota)

Another quick and easy check of a battery's condition is to measure the voltage of the battery with no load connected to it (fig. 11). If the battery has just been charged, turn on the headlights for about one minute to eliminate the surface charge before measuring the voltage. Remember, this test is with no load, so turn off all equipment including the lights before measuring the voltage. A good battery will read 12.6 volts, while a dead battery will read a voltage at or below 12 volts.

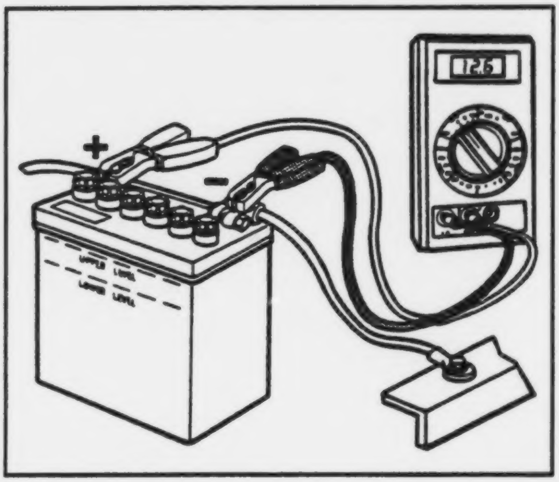


Fig. 11. A voltmeter is used to check voltage. (Courtesy of Toyota)

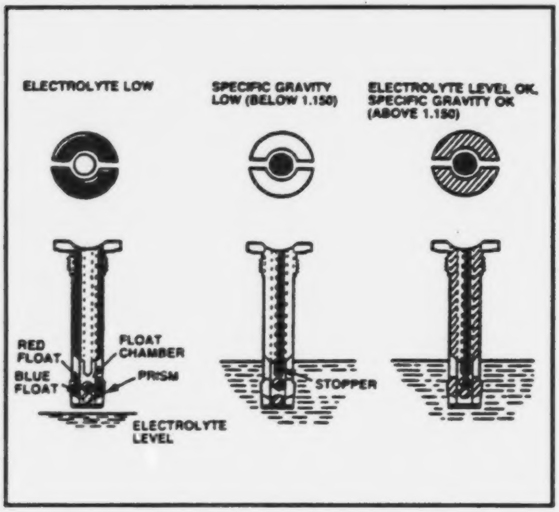

ELECTROLYTE LOW
SPECIFIC GRAVITY LOW (BELOW 1.150)
ELECTROLYTE LEVEL OK, SPECIFIC GRAVITY OK (ABOVE 1.150)
RED FLOAT
FLOAT CHAMBER
BLUE FLOAT
PRISM
ELECTROLYTE LEVEL
STOPPER

Fig. 12. An indicator eye shows the electrolyte level. (Courtesy of Toyota)

Some manufacturers use an indicator eye on their batteries to help check for electrolyte level and the state of the charge. The indicator eye shown in figure 12 will show red if the electrolyte level is low or the cell is severely discharged. A blue color indicates that the electrolyte level is acceptable and the battery has some charge left.

You can conduct an operating test of a battery by cranking the engine with the headlights on. If the headlights dim excessively or behave erratically, then either the battery is weak or there is a poor connection in some of the cables.

Some shops will have equipment to test the battery by putting a heavy load on it and measuring the current flow. If the battery fails this test, it may need to be charged. The three-minute charge test will determine if the battery will accept a charge. This test involves charging the battery for three minutes at a rate of 40 amperes. If the battery voltage exceeds 15.5 volts during this test, the battery may have sulfated. A slow charge may revive a sulfated battery. A voltage reading below 12.6 volts would indicate that the battery is accepting the charge, and the charge should be continued until the battery is fully charged.

Servicing a Battery

When a battery needs a charge, a slow charge is always better, although sometimes there isn't enough time. A fast charge will shorten the battery life. Before doing a fast charge on a battery, the terminals and the top of the battery should be cleaned. All of the vent plugs should be removed to allow any gases to escape. Always connect and disconnect the leads from the charger with the charger off (fig. 13).

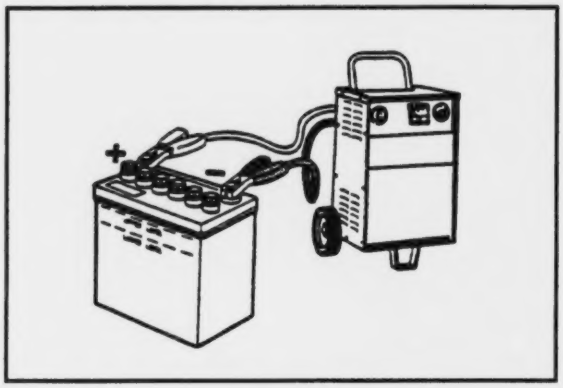


Fig. 13. Use recommended procedures to charge a battery. (Courtesy of Toyota)

The hydrogen gas that will come off the plates during the charging process will explode if it accumulates. Also, oxygen comes off the other plate, which increases the explosive effect of the hydrogen. Keep the area over the battery and around it clear, and avoid any sources of ignition (fig. 14).

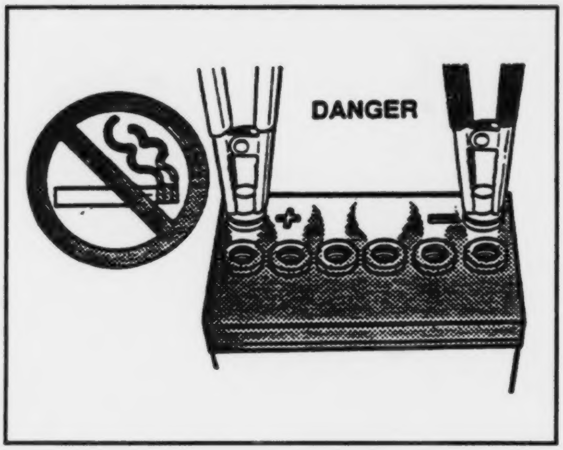


Fig. 14. Do not allow open flame nearby. Never disconnect charger cables while charging. (Courtesy of Toyota)

A slow charge should be done with 1/10 the current of the amp-hour (AH) rating of the battery. A 40 AH hour battery should be charged with 4 amperes.

Many problems that at first appear to be battery problems are, in fact, only dirty battery terminals. A small amount of resistance at the battery terminal will keep the battery from cranking the engine. Clean the terminals carefully, using the appropriate tool (fig. 15). You should be careful not to drop anything into the battery vents.

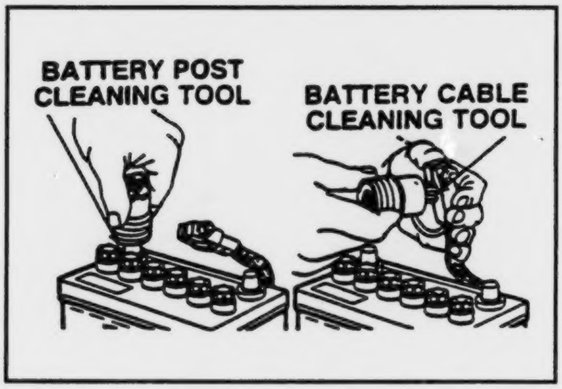


Fig. 15. Cleaning battery posts and cables. (Courtesy of Toyota)

When jump-starting a car with a dead battery, it is important to be careful in the event the battery ruptures and sprays acid around. The vent holes on an old battery can get stopped up. The process of jumping a car can cause a lot of gas to be released from the plates, which could rupture the battery and release the electrolyte which has sulfuric acid in it.

The jumper cables used to jump a battery in a car should be connected as shown in figure 16. Connect the positive cable first, and then touch the ground cable momentarily to the metal of the car and watch for a big spark. A big spark means that the cables may be reversed. Check the polarity carefully and if there is still a big spark, do not continue until the problem is found.

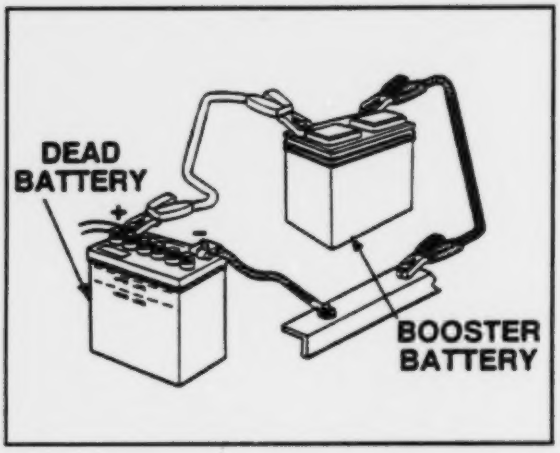


Fig. 16. Connect booster positive cable to the positive battery terminal. Connect the negative cable to metal on the vehicle. (Courtesy of Toyota)

When a battery has to be replaced, you should use a cable puller (see fig. 17) to remove the cables on a top-mounted battery. You should always replace a battery with the correct size and capacity.

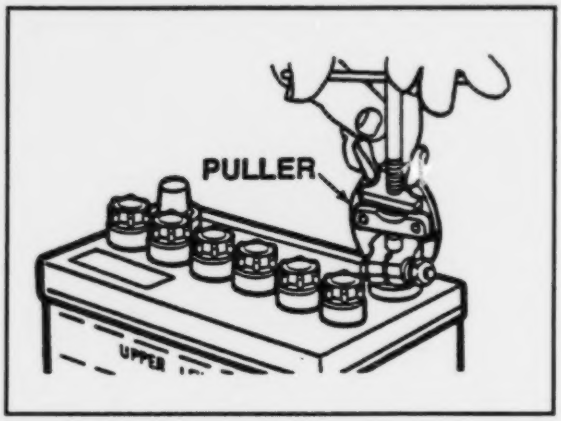


Fig. 17. Use a cable puller to remove a cable from the battery. (Courtesy of Toyota)

Exercise

1. In a fully charged lead acid battery, what is the material made of that coats the positive plate in the battery?
2. What two liquids make up the electrolyte in a lead acid battery?
3. If a battery can deliver 345 amperes at 9.6 volts, what is the power rating of the battery?
4. What is the amp-hour rating of a battery that delivered 1.75 amperes for 20 hours at room temperature?
5. What range of temperatures will have a negligible effect on hydrometer readings?
6. A fully charged good battery should read what voltage?
7. What is the maximum difference in specific gravity readings between cells that can be tolerated before a battery should be replaced?
8. What should the specific gravity of a fully charged good battery be?
9. What color is the negative plate in a fully charged lead acid battery?
10. A lead acid battery has 12.60 volts when it has no load on it. A load is placed across the battery, and the voltage drop across this 0.5 Ω load becomes 12.30 volts. What is the internal resistance of the battery?

D-1 The Battery

Laboratory Experiment

Essential Elements: (gg) (1-4)

Objective

The student will examine and understand the internal resistance of a battery.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 47 Ω resistor
1 DVOM

Procedure

The automotive lead acid battery has a low internal resistance. All batteries have some internal resistance. A perfect voltage source does not have an internal resistance. You can think of a car battery and the flashlight batteries, which you will use with this lab, as perfect voltage sources in series with their internal resistance.

In order to accurately measure the value of the perfect voltage source inside the battery, you need to take an open circuit voltage measurement with a meter that draws very little current. Your DVOM is perfect for this application.

Once you have the open circuit voltage, you have the value of the perfect voltage source inside the battery. Next you will put a load on the battery and measure the output voltage. You will use this output voltage to calculate the current output from the battery. This voltage under load minus the open circuit voltage will give the voltage drop across the internal resistance. The load current which you calculated and the voltage drop across the internal load can be used to find the value of the internal resistance by using Ohm's law.

1. Connect your DVOM, using two jumpers to the 6-volt battery pack, and accurately record the voltage of the battery pack with no load.

2. Switch your DVOM to resistance, and use two jumpers to accurately measure the value of the 47 Ω resistor.

3. Use the jumpers to connect the 47 Ω resistor to the battery pack. Switch your DVOM back to measure voltage, and carefully measure and record the voltage across the load. This is the voltage under load.

4. Now divide the voltage under load by the accurate value of the load resistance (47 Ω). Record this value. This is the current that is passing through the load and through the internal resistance in the battery.

5. Calculate the voltage drop across the internal resistance by finding the difference between the open circuit voltage and the voltage under load. Using Ohm's law again, divide this voltage difference, which is the voltage drop across the internal resistance, by the current that you calculated in part 4. The result is the internal resistance of the battery pack.

D-2

The Charging System

Essential Elements: (gg)(1-4)

Unit Objectives:

After completing this instructional unit, you will be able to explain the functions of:

- *automotive batteries*
- *charging systems*
- *engine starting systems*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how to test the alternator on a car*
- *explainhow to test the charging system*
- *explain how to repair the alternator*

Charging System Design

The alternator is used to supply current to the automobile and charge the battery when the engine is running. The mechanical force from the engine is converted into electrical energy by the alternator.

When the engine is running, the alternator first supplies the electrical needs of the car and then recharges the battery. Figure 1 shows how the alternator is wired into a typical car. Figure 2 shows the location of the components of the charging system in a typical car.

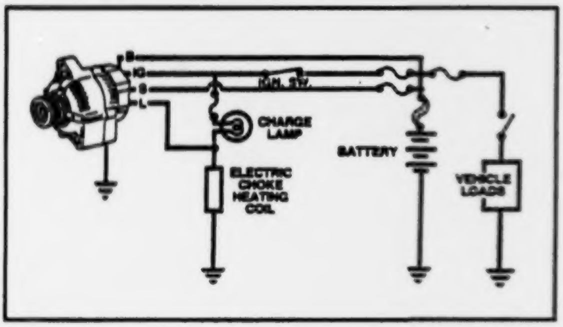

B
IG
S
L
IGN. SW.
CHARGE LAMP
BATTERY
ELECTRIC CHOKE HEATING COIL
VEHICLE LOADS

Fig. 1. Alternator electrical schematic. (Courtesy of General Motors Corp.)

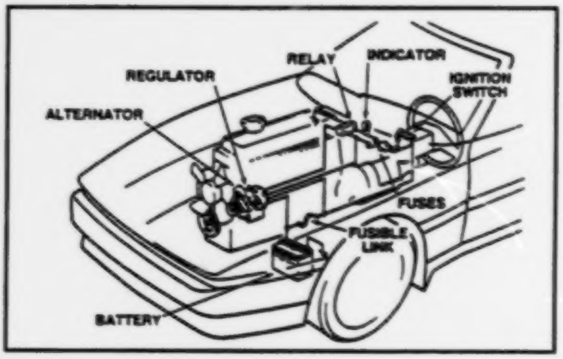

REGULATOR
RELAY
INDICATOR
IGNITION SWITCH
ALTERNATOR
FUSES
FUSIBLE LINK
BATTERY

Fig. 2. Location of components of a charging system. (Courtesy of General Motors Corp.)

The ignition switch in the charging system energizes the alternator. If the battery is removed and the alternator is spun, the alternator will not produce any electricity. It has to be energized first.

The alternator shown in figures 1 and 2 has a built-in rectifier and voltage regulator. This allows the alternator to produce a constant dc voltage. The battery is located close to the alternator, and this car shows an indicator light or charge lamp in the circuit. Some manufacturers use an ammeter in series with the battery, and others use a voltmeter across the battery. Notice the many fuses and fusible links that are used to protect the system.

Alternator Theory

When a conductor is moved in a magnetic field so that it is cutting the magnetic lines of force, a voltage will be induced in the conductor.

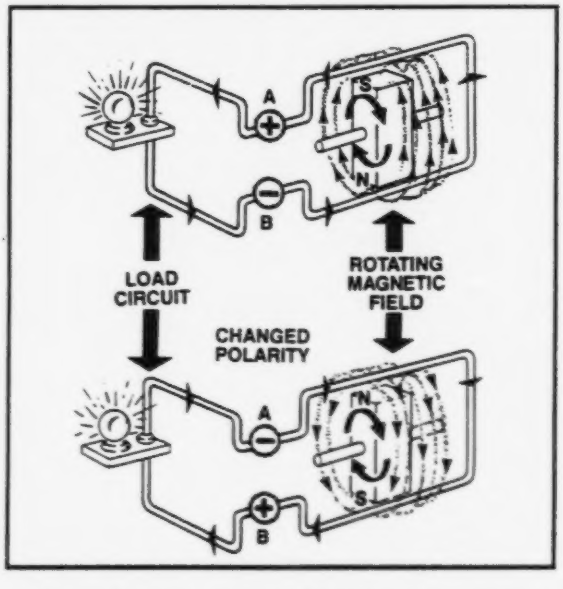


Fig. 3. Magnetic lines of force rotating across a conductor induce a voltage. (Courtesy of General Motors Corp.)

If we rotate a bar magnet inside a loop of wire (fig. 3), a voltage will be induced in the wire. When the bar magnet has its south pole on top and the north pole at the bottom, as shown in the top part of figure 3, the current flow will be as shown in the drawing. When the bar magnet is horizontal in the process of turning, the voltage induced will have dropped to zero. As the bar magnet continues to turn, the magnetic lines of force will again start to cut the conductor and cause current to flow in the other direction, as shown in the bottom half of figure 3.

The bar magnet spinning in the loop of wire will alternately change the direction of current flow in the wire. This small alternator is generating alternating current.

Rotating a bar magnet inside a single loop of wire is not very efficient. The performance of this alternator can be improved by enclosing the magnet and loop of wire inside an iron frame (see fig. 4).

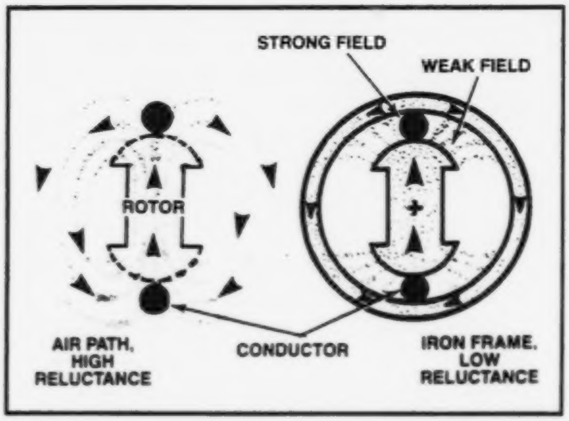


Fig. 4. Electromagnetic assembly. (Courtesy of General Motors Corp.)

The iron frame around the loop and magnet conducts the lines of magnetic force and concentrates them, as well as providing support for the loop of wire. The iron frame causes the wire loop to cut many more lines of force as it revolves.

The more magnet lines of force that are cut by the loop, the more voltage is induced in the loop of wire. The number of magnetic lines of force that are cut can be increased by increasing the number of loops, increasing the speed at which the magnet rotates, or increasing the magnetic force of the magnet. Since the number of loops is fixed in the alternator by design, and since the speed of rotation is determined by the engine speed, this leaves only the strength of the magnetic force that can be increased.

The magnetic force that revolves in an alternator is created by the current from the battery. The amount of magnetic force is controlled by the voltage regulator. Controlling the magnetic force that revolves in the alternator is an effective method for controlling the output voltage of the alternator.

Alternator Construction

The part of the alternator that provides the magnetic force and rotates is called the **rotor** (fig. 5).

It has a coil of wire with a large number of turns enclosed in two iron pole pieces with interlacing fingers. This assembly is mounted on the rotor shaft. A strong electromagnet results when current passes through the coil, as shown in figure 6. The fingers on the pole pieces surrounding the coil alternately become north and south poles.

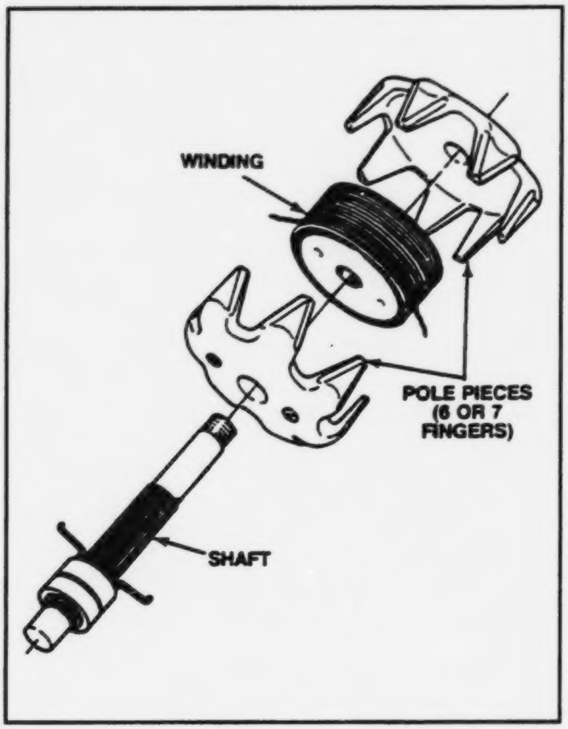


Fig. 5. Rotor. (Courtesy of General Motors Corp.)

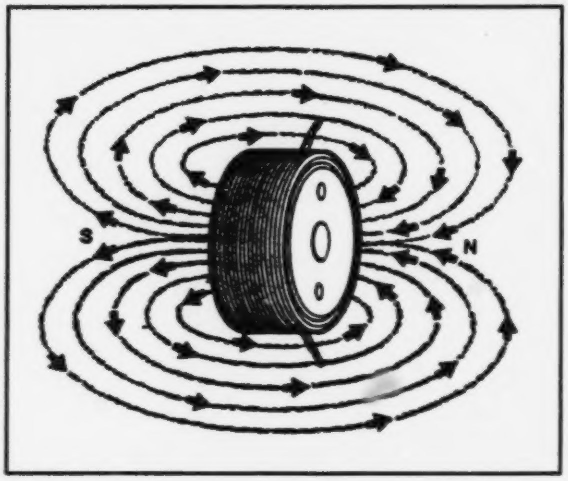


Fig. 6. Rotor core. (Courtesy of General Motors Corp.)

The wires from the core run along the shaft, on the rotor, to the copper slip rings (fig. 7). The slip rings are insulated from the shaft and each other. Each slip ring is connected to one wire from the coil. Pieces of carbon called carbon brushes make contact with the slip rings while the rotor is spinning, providing a path for the current to the rotor.

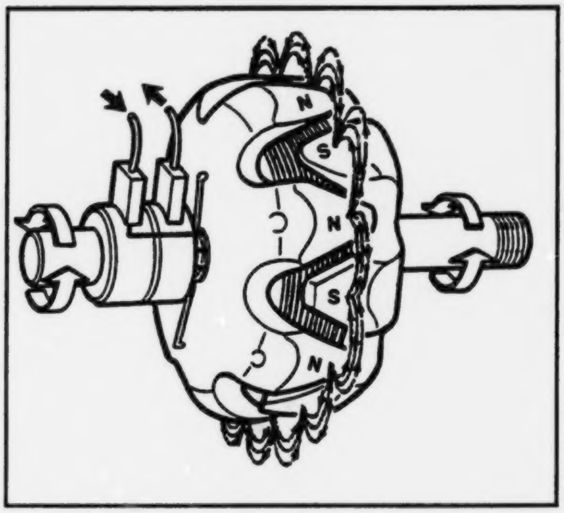


Fig. 7. Rotor circuit. (Courtesy of General Motors Corp.)

In the previous example of the bar magnet spinning inside a loop, the bar magnet is the rotor, and the loop that has the voltage induced in it is called the *stator*. The stator has many turns of wire mounted in an iron ring (see fig. 8).

The typical stator has three windings consisting of many turns of wire in each winding. The three windings are mounted in the iron frame so that the magnetic polarity is the same on all of the coils within each winding at any time.

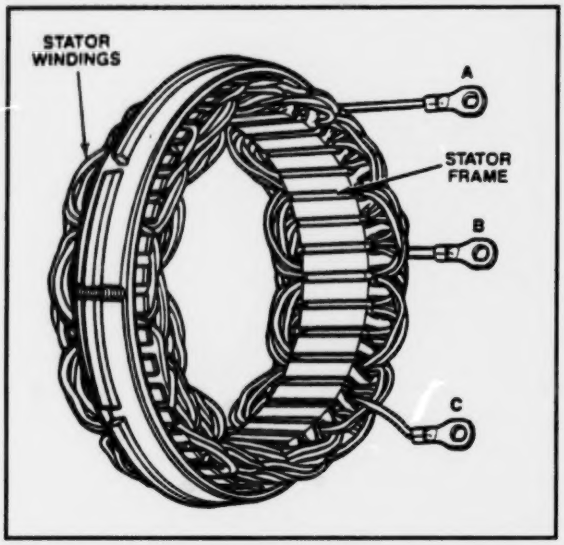

STATOR WINDINGS
A
STATOR FRAME
B
C

Fig. 8. Complete stator assembly. (Courtesy of General Motors Corp.)

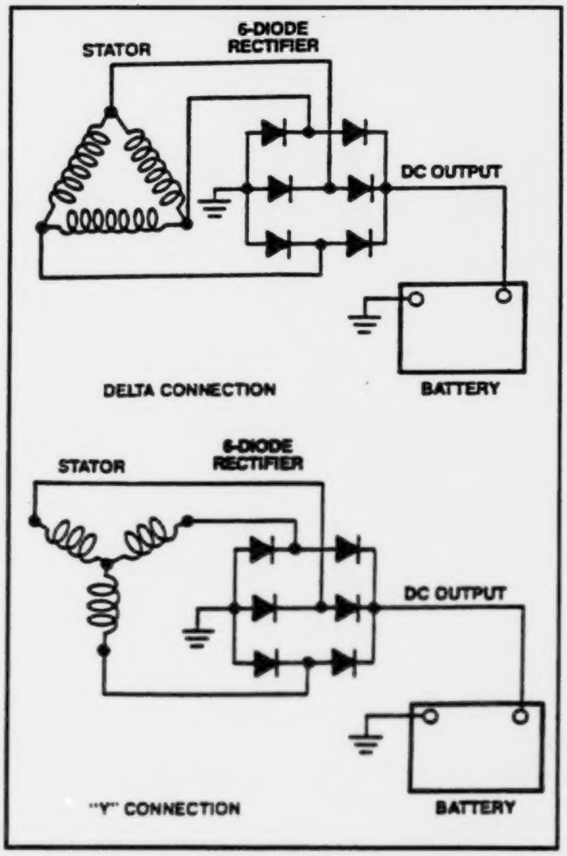

STATOR
6-DIODE RECTIFIER
DC OUTPUT
DELTA CONNECTION
BATTERY
STATOR
6-DIODE RECTIFIER
DC OUTPUT
"Y" CONNECTION
BATTERY

Fig. 9. Stator windings. (Courtesy of General Motors Corp.)

The three windings are connected together (fig. 9), as either a "Y" connection or the DELTA connection.

The current coming from the stator is alternating in polarity or ac. Notice, in figure 9, that six diodes change the direction of current flow, resulting in dc or direct current.

Figure 10 shows the path of current off one winding to help you see how the current is directed in one direction as a result of the diodes. If you use an oscilloscope to look at the output current that is directed to the battery, it would look like the drawing at the bottom of figure 10.

The current coming from one winding will look like the graph in figure 11. This is called a *sine wave,* and it consists of one cycle or revolution of the simple alternator.

Notice that the graph of the sine wave has both positive and negative values and is marked in degrees. Each of the three windings will produce a sine wave (fig. 11), and they will all be out of phase with each other. This means they will all cross the zero voltage line at different times (fig. 12).

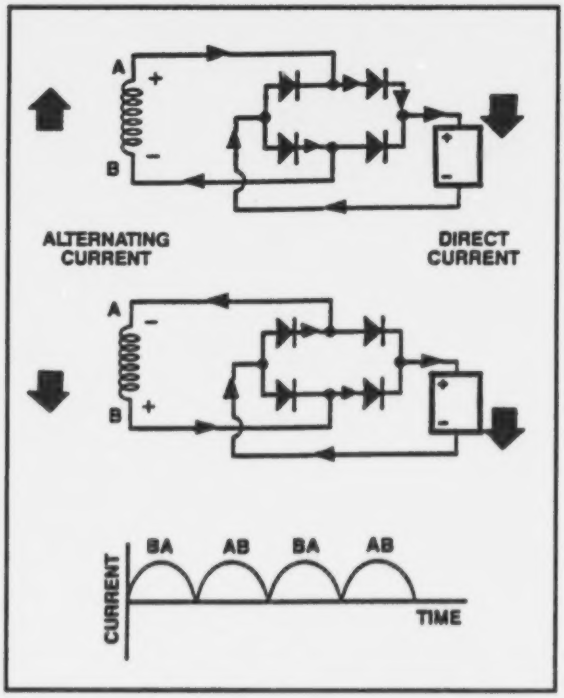

A
+
-
B
ALTERNATING CURRENT
DIRECT CURRENT
A
-
B
+
BA
AB
BA
AB
CURRENT
TIME

Fig. 10. Diode rectifiers. (Courtesy of General Motors Corp.)

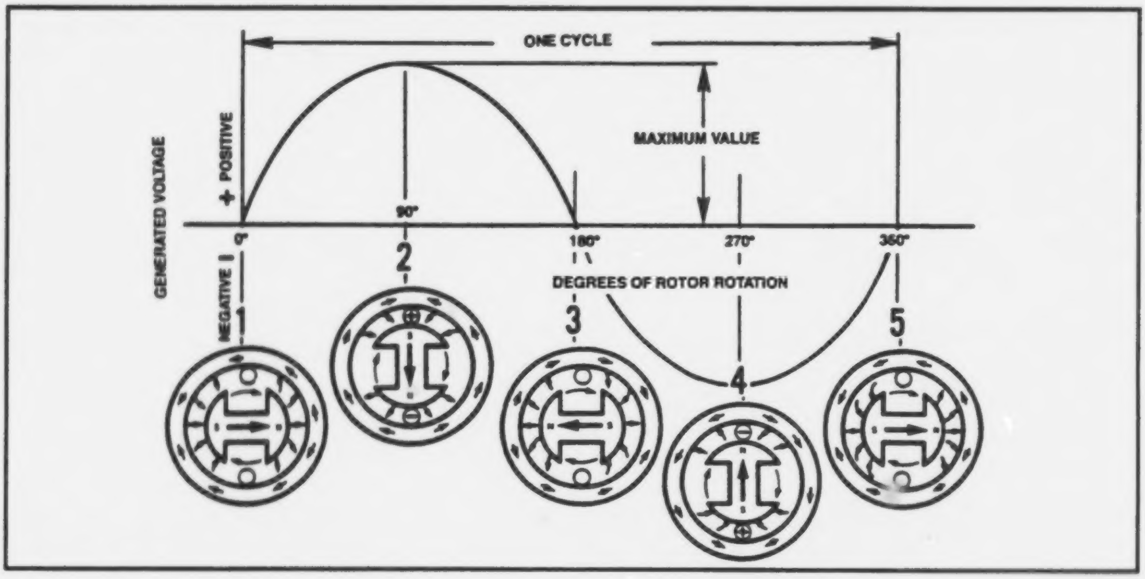

ONE CYCLE
MAXIMUM VALUE
GENERATED VOLTAGE
+ POSITIVE
NEGATIVE
90°
0°
180°
270°
360°
DEGREES OF ROTOR ROTATION
1
2
3
4
5

Fig. 11. Rotor cycle. (Courtesy of General Motors Corp.)

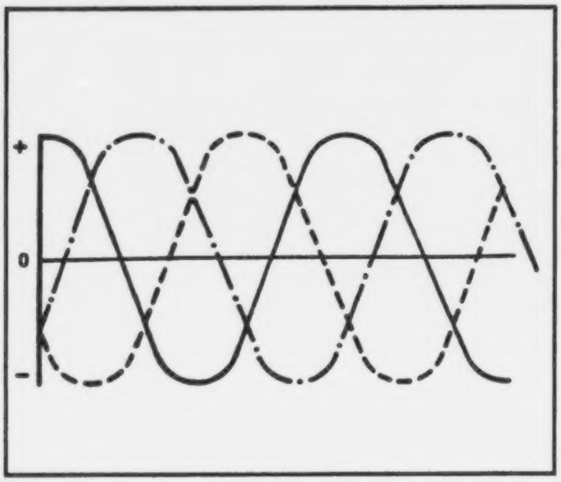


Fig. 12. Three-phase voltage graph. (Courtesy of General Motors Corp.)

The combined ac output is called three-phase current since there are three sine waves all at a different phase with respect to each other. The diodes in the rectifier, as you have learned earlier, only allow the current to travel in one direction. According to conventional current flow, the direction of current flow is with the arrow (fig. 13).

The diodes used in alternators look different than the diodes you have used in your laboratory, although they operate in the same manner. Some typical automotive diodes are shown in figure 14.

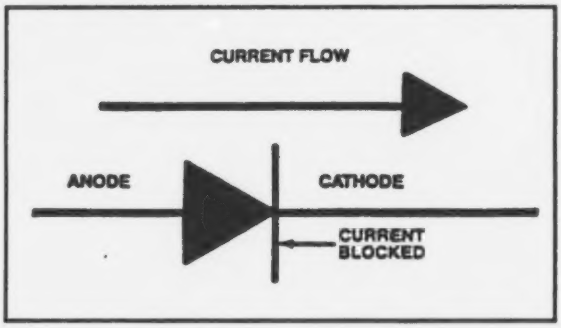


Fig. 13. Diode symbol. (Courtesy of General Motors Corp.)

The diodes are mounted in the rectifier bridge (fig. 15). The bridge is composed of two heat sinks. One of the heat sinks is grounded to the alternator, and the other is insulated from the alternator.

The voltage regulator, which is usually a solid-state IC regulator mounted on the alternator, is shown in figure 16. The old-style voltage regulator is shown above it in figure 16.

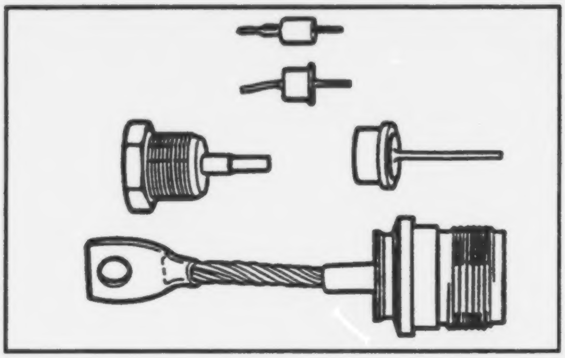


Fig. 14. Typical diodes. (Courtesy of General Motors Corp.)

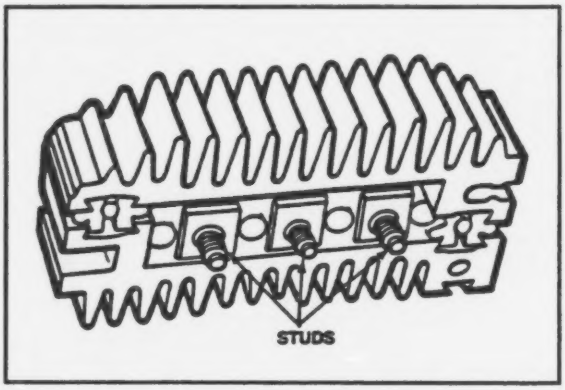


Fig. 15. Rectifier bridge. (Courtesy of General Motors Corp.)

Remember that, as the current to the rotor is increased, more magnetic force will be generated by the rotor, increasing the number of magnetic lines of force. This increase in the number of magnetic lines of force results in more voltage induced in the stator. The voltage regulator controls the current sent to the rotor, which results in control of the output voltage from the stator or the alternator.

The voltage on a fully charged battery is 12.6 volts. The voltage that most regulators are set at is around 14.7 volts (fig. 17). This 14.7 volts from the alternator will charge the battery and supply the current for all of the loads on the car.

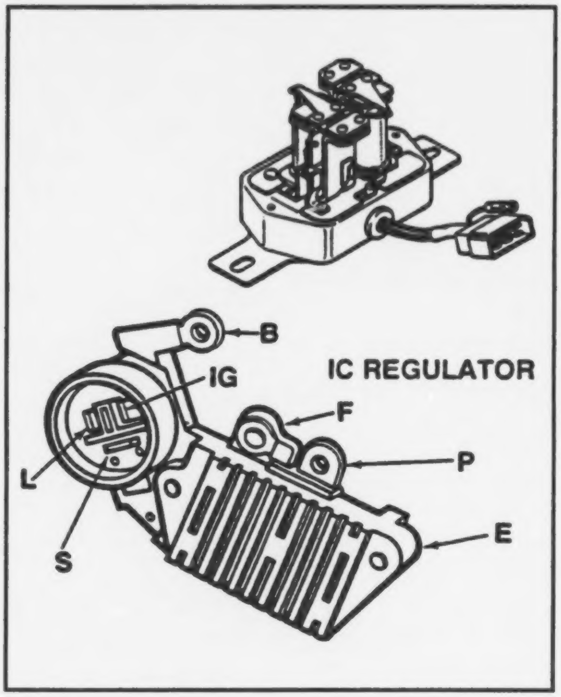


Fig. 16. Electromechanical regulator. (Courtesy of Toyota)

Alternator Circuitry

A typical alternator circuit diagram is shown in figure 18. This diagram shows the "Y"-connected stator connected to the rectifier bridge.

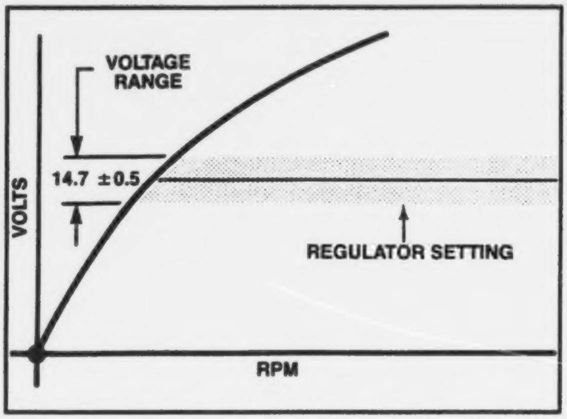


Fig. 17. Voltage regulation. (Courtesy of General Motors Corp.)

The three connections outside the dotted line are the connections from the alternator to the battery and indicator lamp. A fourth connection is the ground connection to the alternator case.

When the ignition switch is closed, current flows through the indicator lamp into terminal 1 on the alternator, through the rotor coils, and through transistor TR_1 to ground. The current also travels in a parallel path through resistor R_1, transistor TR_3, transistor TR_1, and then back to ground or the negative terminal of the battery. Resistor R_6 carries some of the current from the indicator lamp.

The battery connection through terminal 2 provides the sense voltage that controls the regulator. Resistor R_2 is a thermistor that changes its resistance value with changes in temperature. This change in resistance from R_2 allows the alternator to change its voltage output, charging the battery at the optimum rate for the temperature.

Figure 19 shows a voltage regulator which uses an integrated circuit to control the voltage. The dotted line with the arrows shows the current flow when the ignition is turned on and the engine has not been started.

The box labeled MIC is the integrated circuit in the voltage regulator for this alternator circuit.

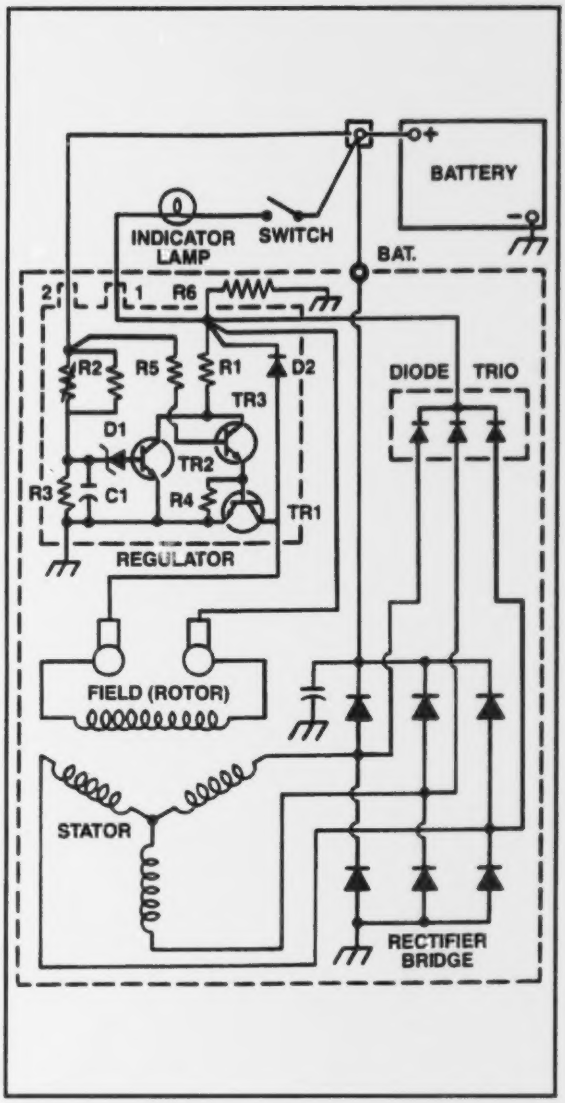


Fig. 18. Typical wiring diagram showing internal circuits. (Courtesy of General Motors Corp.)

Troubleshooting the Charging System

To effectively troubleshoot a charging system, it is important to understand the charging system for that car model and manufacturer. If the system has a warning light, most manufacturers connect the warning light in series with the rotor. This means that if the light does not come on when the key is first turned on, the alternator will not be working. The problem can be as simple as a blown fuse or burnt-out light.

If the warning light does not go out after the engine is running, the problem could be bad connections to the battery or a loose fan belt. Checking the wiring diagram for that particular car can show you a lot more possibilities for a warning light that does not go out.

Usually, the first thing that you should do when troubleshooting a failed charging system is to make a careful visual inspection (see fig. 20).

First determine if the problem has resulted in a discharged battery by checking the state of charge. If there are no removable vent covers, then check the state of charge with a voltmeter, or watch the headlights while someone starts the car. Next check the fuses and fusible links, then the drive belt for tension and wear. Finally, check the alternator and the warning light.

If the visual check showed that the battery was discharged, then with the discharged battery, start the engine. Jump-start the car if necessary. Connect your DVOM or other good voltmeter across the battery, and check the voltage. A discharged battery will have less than 12.6 volts on it; however,

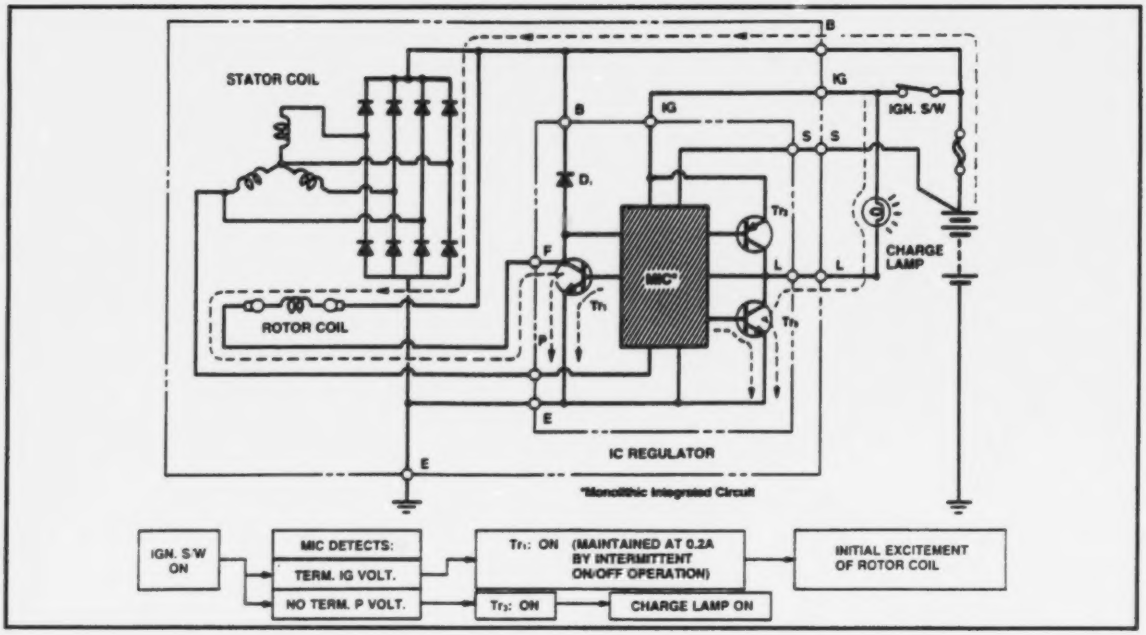

B
IG
IGN. S/W
STATOR COIL
B
IG
S
S
D.
Tr2
CHARGE LAMP
F
MIC*
L
L
Tr1
ROTOR COIL
P
Tr3
E
IC REGULATOR
E
*Monolithic Integrated Circuit
IGN. S/W ON
MIC DETECTS:
TERM. IG VOLT.
NO TERM. P VOLT.
Tr1: ON (MAINTAINED AT 0.2A BY INTERMITTENT ON/OFF OPERATION)
INITIAL EXCITEMENT OF ROTOR COIL
Tr2: ON
CHARGE LAMP ON

Fig. 19. A typical alternator circuit diagram. (Courtesy of Toyota)

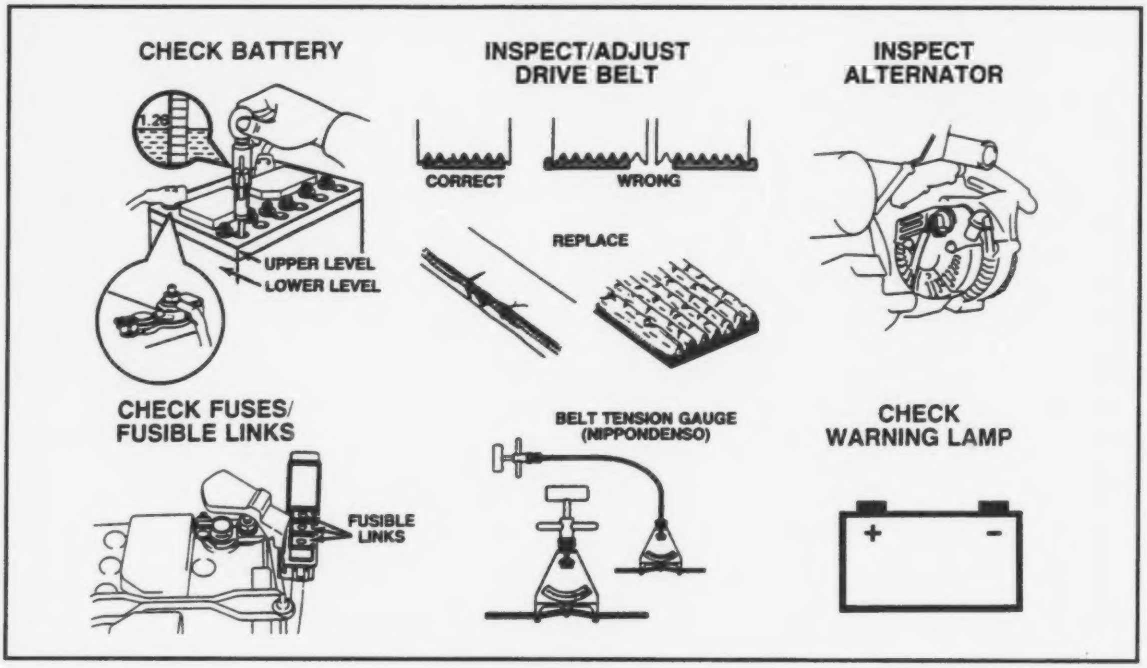

CHECK BATTERY
1.20
UPPER LEVEL
LOWER LEVEL
INSPECT/ADJUST DRIVE BELT
CORRECT
WRONG
REPLACE
INSPECT ALTERNATOR
CHECK FUSES/ FUSIBLE LINKS
FUSIBLE LINKS
BELT TENSION GAUGE (NIPPONDENSO)
CHECK WARNING LAMP
+
−

Fig. 20. Troubleshooting points.
(Courtesy of Toyota)

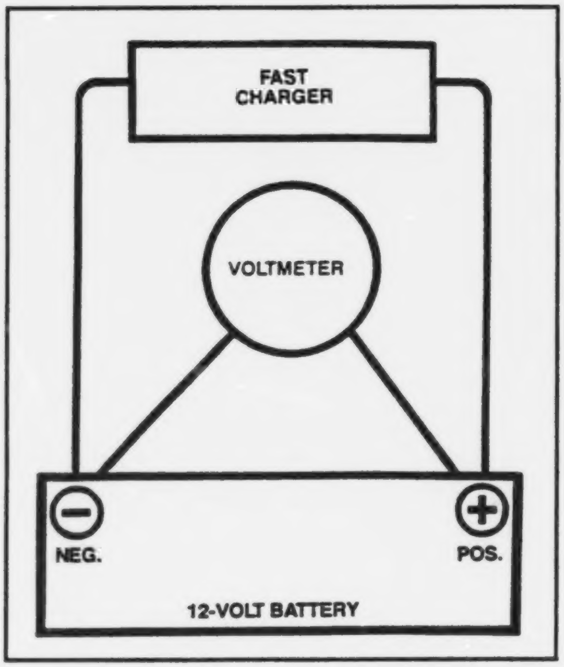


Fig. 21. On-car voltage regulator test. (Courtesy of General Motors Corp.)

with the alternator running at a fast idle, the voltage should be over 12.6 volts. With a fast idle, check the voltage with the lights and all other electrical loads turned on. If the engine is at a fast idle, the alternator should be able to keep the voltage above 12.6 volts.

If the alternator cannot keep up with the load, even at a fast idle, then the voltage regulator and the alternator should be checked. The voltage regulator can be checked by connecting a voltmeter or your DVOM to the battery and a fast charger to the battery (fig. 21). As the fast charger is increased, the warning light should go out when the voltage regulator setting is reached. You can confirm this by reading the voltage on the battery with your DVOM when the warning light starts to dim.

A bolt-on voltage regulator can be removed from the alternator and checked by hooking it to a battery and a fast charger (fig. 22).

Connect the test light to the voltage regulator (fig. 22), and start increasing the charger rate. The test light is connected to the voltage regulator where the rotor would be connected. When the voltage across the battery reaches the voltage regulator setting, the test light should go out. This voltage should be more than 13 volts and less than 16 volts.

Once you have confirmed that the alternator has failed, it should be removed and bench-tested and repaired. Start by disassembling the alternator, and perform a visual check for any obvious problems.

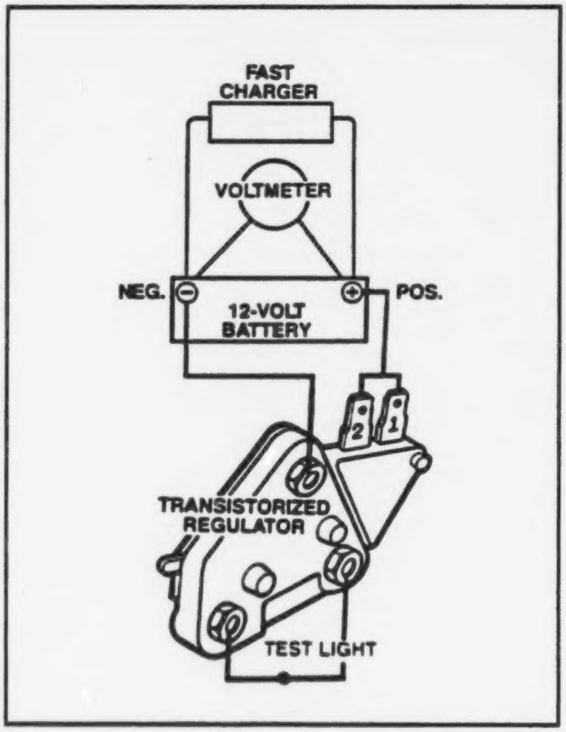


Fig. 22. Off-car voltage regulator test. (Courtesy of General Motors Corp.)

Check the rotor for an open circuit by checking the continuity between the slip rings (fig. 22). There should be a small amount of resistance from the windings. If there is no continuity (infinite resistance), this indicates an open in the windings. The rotor should be replaced.

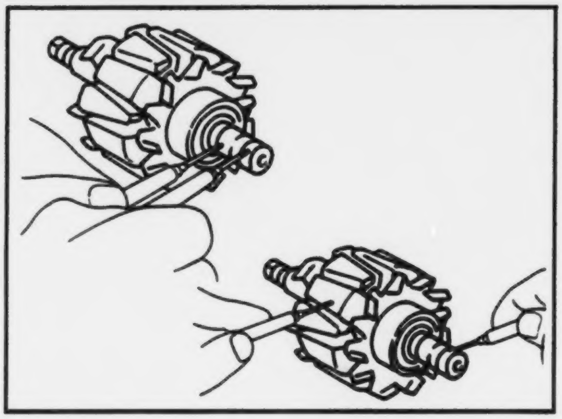


Fig. 23. Rotor tests. (Courtesy of Toyota)

Check the continuity between the slip rings and the rotor (fig. 23). There should be no continuity. Any resistance between the slip rings and the rotor indicates a short to ground. The rotor should be replaced if there are any shorts to ground.

If the rotor checks out, then the stator should be tested. The stator should be tested (fig. 24), by testing for continuity between the leads and confirming that there is no resistance from the leads to the stator core. The stator should be replaced if any opens or shorts are detected with these tests.

If the rotor and stator have checked out, then the alternator should be assembled, and an oscilloscope should be used to look at the output voltage from the alternator while it is running in a test setup. The various patterns and what they indicate are shown in figure 25.

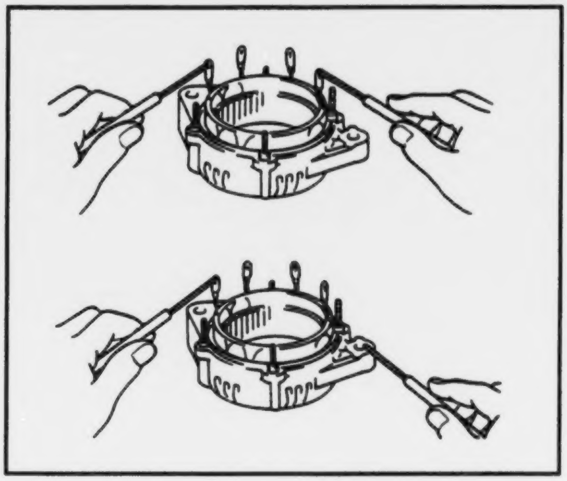


Fig. 24. Stator tests. (Courtesy of Toyota)

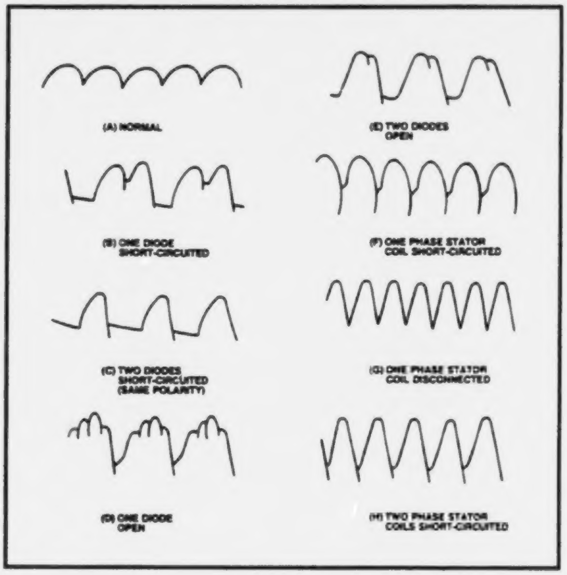


Fig. 25. Scope testing. (Courtesy of Toyota)

If the scope test shows a problem with the diodes, then your DVOM can be used to determine which diodes have failed. Use the diode test function on the meter to get enough voltage to overcome the junction in the diode. Check each diode (figs. 26 and 27), by testing it in both directions.

In one direction, the diode should have some resistance; in the other, it should show as an open. If it shows the same in both directions either open or shorted, the diode is bad and should be replaced.

Exercise

1. A technician obtains a new alternator off the shelf and puts it on the bench to test it. The technician connects the DVOM to the stator and spins the rotor. There is no voltage reading on the meter. Why does the DVOM show no voltage with the rotor spinning on a new good alternator?

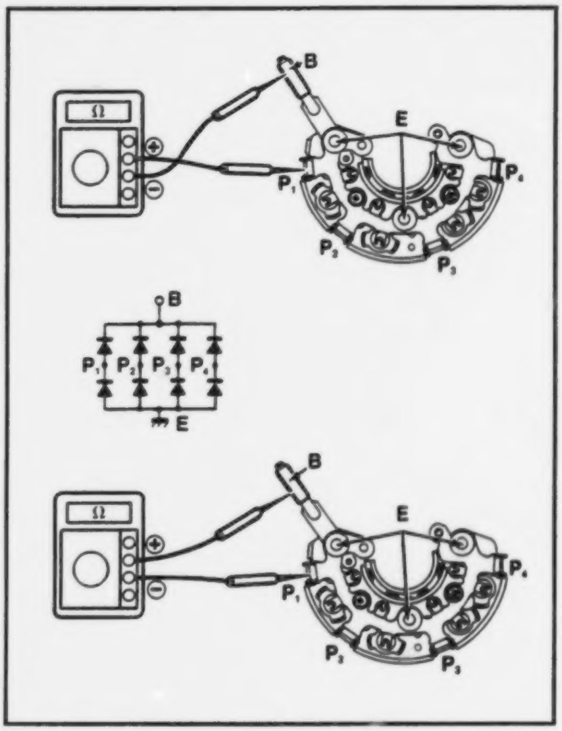


Fig. 26. Testing diodes on the positive side of the rectifier. (Courtesy of Toyota)

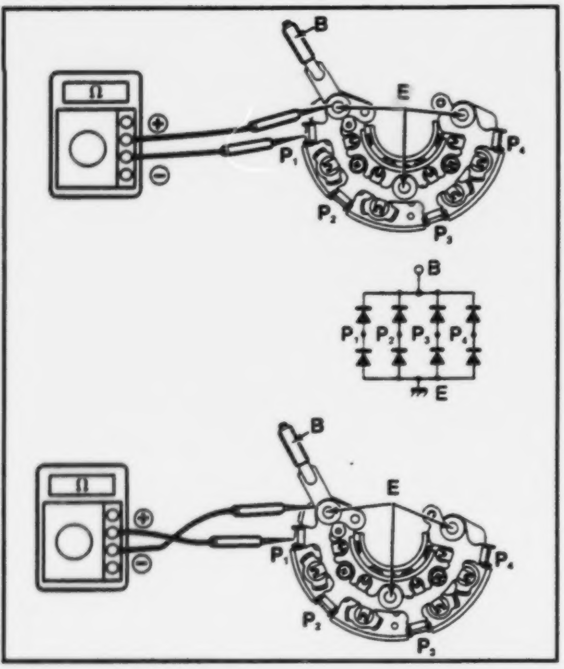


Fig. 27. Testing diodes on the negative side of the rectifier. (Courtesy of Toyota)

2. If the voltage regulator failed, allowing excessive current into the rotor, what kind of damage would result?

3. What three things in the design of an alternator will increase its performance?

4. What should the voltage on a fully charged battery be?

5. If the indicator lamp burns out in a charging system, what happens to the alternator?

6. How can the driver tell when the belt driving the alternator breaks while the car is traveling down the road?

7. In figure 28, what would happen to the current through the field coil if the zener diode shorted?

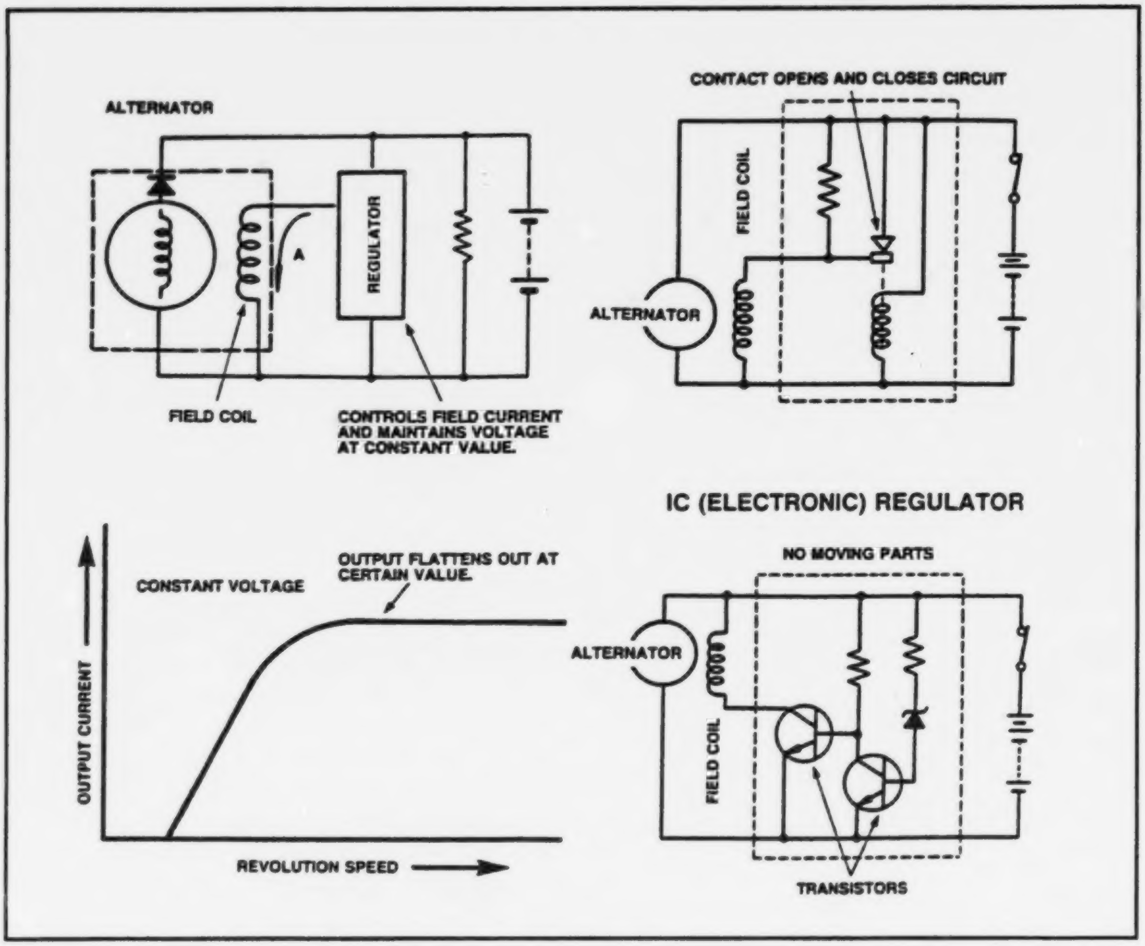

ALTERNATOR
A
REGULATOR
FIELD COIL
CONTROLS FIELD CURRENT AND MAINTAINS VOLTAGE AT CONSTANT VALUE.
CONTACT OPENS AND CLOSES CIRCUIT
FIELD COIL
ALTERNATOR
IC (ELECTRONIC) REGULATOR
NO MOVING PARTS
ALTERNATOR
FIELD COIL
TRANSISTORS
CONSTANT VOLTAGE
OUTPUT FLATTENS OUT AT CERTAIN VALUE.
OUTPUT CURRENT
REVOLUTION SPEED

Fig. 28. Electromechanical regulator. (Courtesy of Toyota)

D-2 The Charging System

Laboratory Experiment

Essential Elements: (gg)(1-4)

Objective

In this lab, the student will examine the rectifier circuit used in an alternator.

Equipment

1 6-volt voltage source (batteries and battery holder)
4 diodes
1 1 kΩ resistor
1 DVOM

Procedure

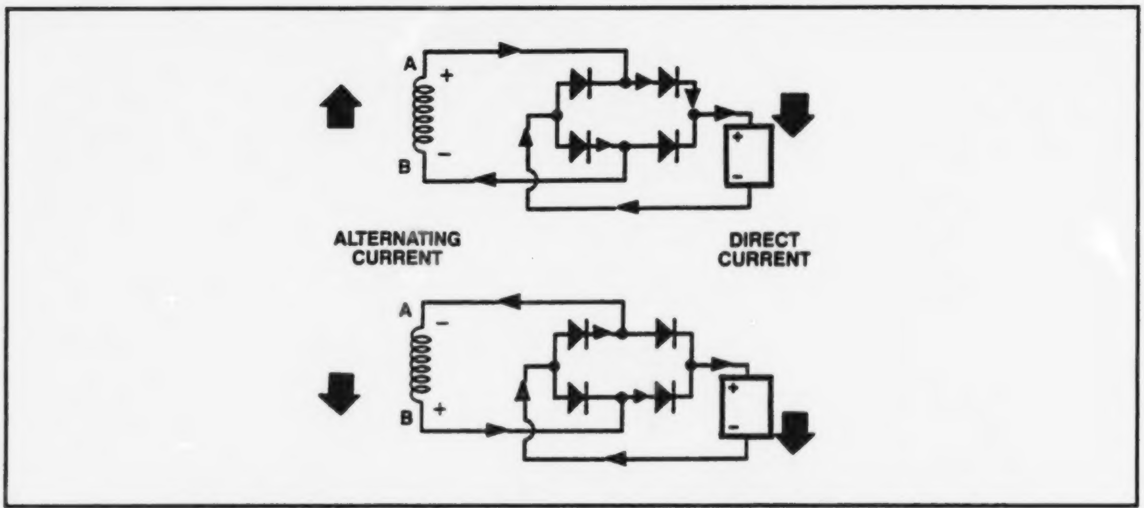


Fig. 1. Diode rectifiers. (Courtesy of General Motors Corporation)

Figure 1 shows a typical rectifier circuit that would be part of an alternator. For this laboratory, you will substitute your 6-volt supply for the winding shown from point A to B. Substitute a 1 kΩ resistor for the box illustrating the battery in the drawing.

1. Draw the schematic using the symbol for a voltage source and resistor where you are going to substitute them for the drawing at the top of figure 1.

2. Build the circuit that you have drawn in part 1.

3. Connect your DVOM's negative lead to the bottom of the 1 kΩ resistor, where figure 1 shows a negative terminal on the battery, and use the positive lead to measure the voltages at all nodes. A node is where any component is connected or there is a connection between conductors. Record all of these voltage measurements with the polarity on your drawing.

4. Trace out the current path on your drawing based on the voltage measurements that you have recorded on the drawing.

5. Reverse the polarity on the 6-volt battery pack according to the drawing at the bottom of figure 1, and draw the schematic. Follow parts 1 through 4 above for the reverse polarity.

The current through the 1 kΩ resistor should always travel in the same direction, or from the top to the bottom as shown in figure 21 in the assignment.

D-3

The Cranking System

Essential Elements: (gg)(1-4)

Unit Objectives:

After completing this instructional unit, you will be able to explain the functions of:

- *automotive batteries*
- *charging systems*
- *engine starting systems*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain the procedures for troubleshooting the starter motor on a car*
- *explain the procedures for troubleshooting the engine starting system*

Engine Starting System

The most important function for the battery and the electrical system is to start the engine. The electrical system starts the engine by first converting electrical energy to mechanical energy in the starter motor, and then providing the electrical energy for the spark plugs and fuel delivery. This assignment concerns the starter motor and the system that controls and engages it.

When the ignition switch is turned on, the battery supplies current to the magnetic switch or solenoid on the starter motor, which engages and draws current from the battery to crank the engine (fig. 1).

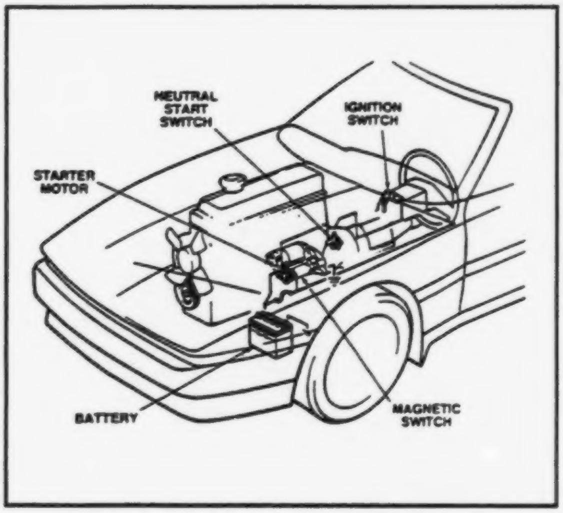


Fig. 1. Cranking circuit. (Courtesy of Toyota)

Most manufacturers put various safeguards into the starting circuit. For cars with automatic transmissions (fig. 2), there is a switch that will only close when the transmission is in neutral, and for some standard transmissions (fig. 3), there is a switch that will only close when the clutch is depressed. The safety cancel switch shown in figure 3 is for four-wheel drive vehicles that need to be started on a hill.

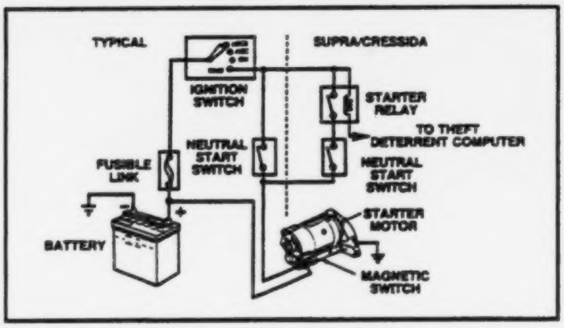

TYPICAL
SUPRA/CRESSIDA
IGNITION SWITCH
STARTER RELAY
TO THEFT DETERRENT COMPUTER
NEUTRAL START SWITCH
FUSIBLE LINK
NEUTRAL START SWITCH
STARTER MOTOR
BATTERY
MAGNETIC SWITCH

Fig. 2. Cranking circuit for Toyota models with automatic transmissions. (Courtesy of Toyota)

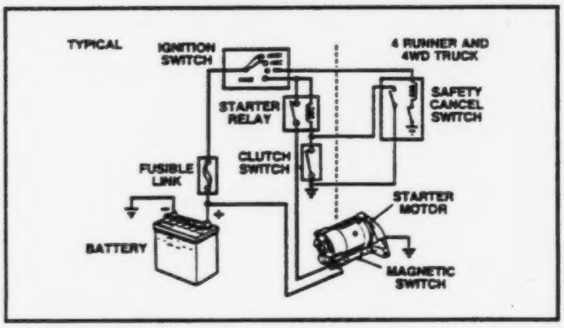

TYPICAL
IGNITION SWITCH
4 RUNNER AND 4WD TRUCK
STARTER RELAY
SAFETY CANCEL SWITCH
CLUTCH SWITCH
FUSIBLE LINK
STARTER MOTOR
BATTERY
MAGNETIC SWITCH

Fig. 3. Cranking circuit for Toyota models with manual transmissions. (Courtesy of Toyota)

Electric Motor Theory

In a previous assignment, you learned that current in a conductor will generate a magnetic force around that conductor. When a conductor that is carrying current is put in a magnetic field (fig. 4), the two magnetic fields push the conductor.

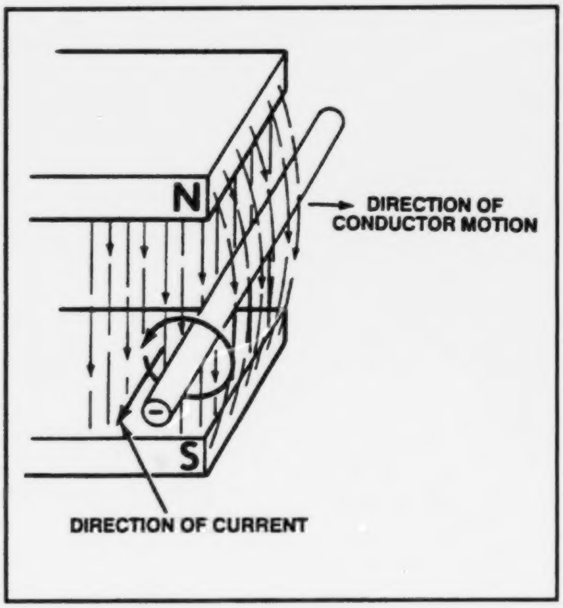

N
S
DIRECTION OF CONDUCTOR MOTION
DIRECTION OF CURRENT

Fig. 4. Conductor held in a magnetic field. (Courtesy of General Motors Corp.)

Figure 4 shows the current traveling toward us, which results in magnetic lines of force as shown in the diagram. These magnetic lines of force distort the lines of force from the horseshoe magnet that is above and below the conductor (fig. 5). Since magnetic lines of force will try to straighten themselves, the larger number of bent lines of force on the inside will push the conductor toward the outside of the horseshoe magnet.

A simple motor is shown in figure 6. The conductor is a bent wire in the shape of a "U," connected to two halves of a split copper ring. The two carbon brushes connected to the battery and the magnet complete this simple motor.

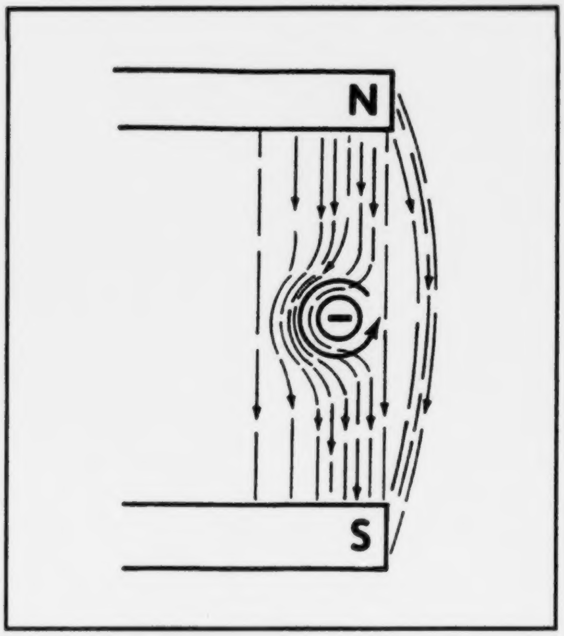


Fig. 5. Magnetic field around a conductor.
(Courtesy of General Motors Corp.)

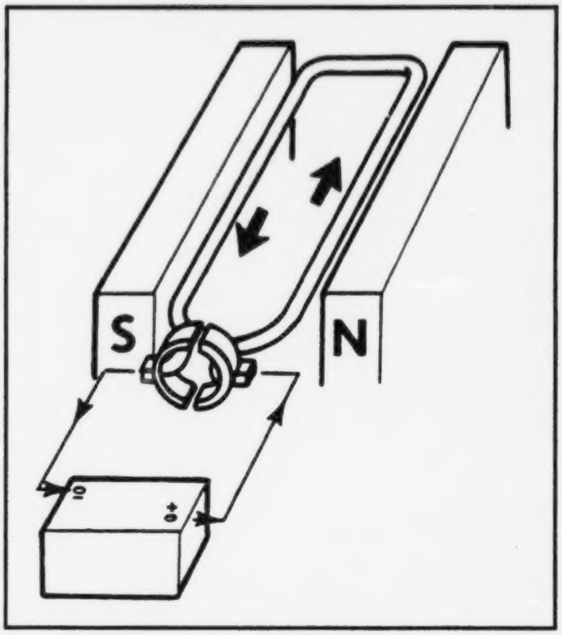


Fig. 6. Basic electric motor.
(Courtesy of General Motors Corp.)

The split ring, which is called a *commutator*, and the U-shaped conductor spin inside the magnet. The current from the battery flows into the split ring on the right side, through the conductor, and out the split ring on the left side (fig. 6). The current flowing through the conductor generates a magnetic force, which distorts the magnetic force from the magnet. This causes the left side of the conductor loop to be pushed down and the right side to be pushed up. As the conductor loop rotates, the split ring changes the current direction in the loop, causing it to continue to rotate.

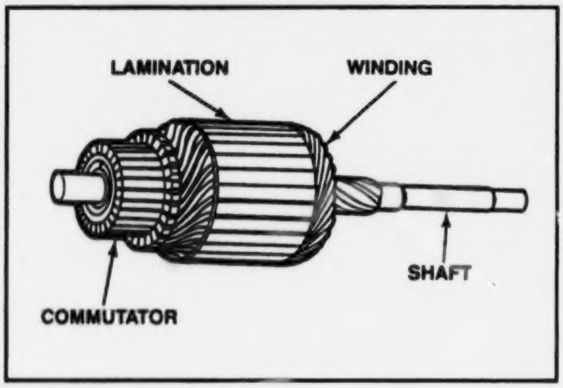


Fig. 7. Armature.
(Courtesy of General Motors Corp.)

A starter motor needs a lot of power to crank an engine. This power is obtained by using more loops or windings (fig. 7). Iron laminations are located over the steel shaft. The windings are copper ribbons placed in the slots between the iron laminations and soldered to the commutator bars. Each of the commutator bars is electrically insulated from the others. This whole assembly is called the *armature*.

The starter motor has to deliver a lot of force to crank an engine. To obtain this force, it is necessary to have a strong magnetic field around the armature. This strong magnetic field is generated by field windings (fig. 8). The current passes through the field windings before it goes to the armature. Figure 8 shows a simplified motor to illustrate how the field windings work.

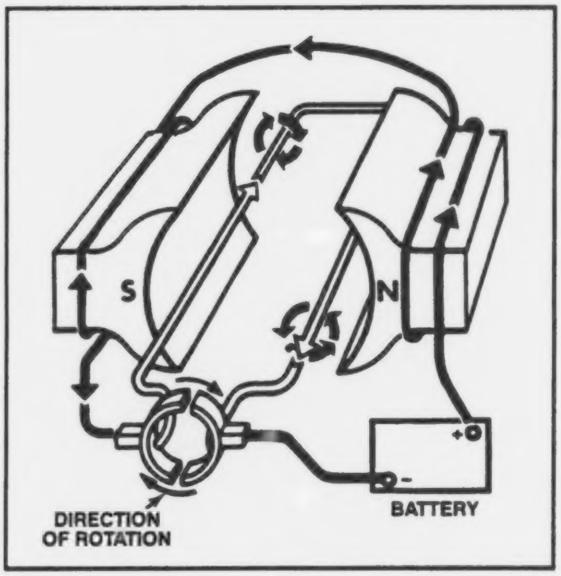

S
N
DIRECTION OF ROTATION
BATTERY
+
-

Fig. 8. Current flow in a motor. (Courtesy of General Motors Corp.)

Notice that the motor in figure 8 shows the field windings and the windings on the armature all in series. This type of motor is called a *series motor*. The individual magnets shown in figure 8 are assembled in the field frame, which becomes part of the magnet, as shown in figure 9.

The complete assembly shown in figure 9 becomes the starter motor that is shown in figure 10. This drawing shows the mechanical details and the magnetic switch or solenoid mounted on top.

When current is passing through the armature and field windings and the armature is spinning, the magnetic forces on the windings in the armature induce a counter electromotive force or voltage called CEMF. This CEMF will oppose the voltage that is pushing the current through the windings in the armature. The result is that the current is reduced in the windings as the armature spins.

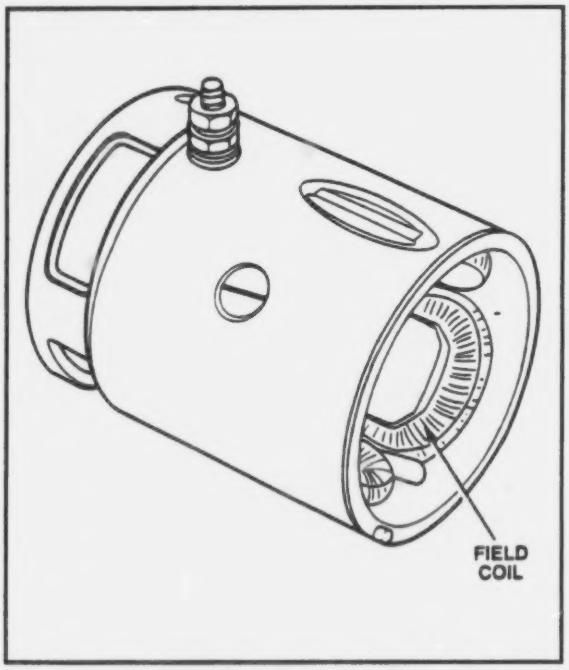


Fig. 9. Field frame assembly. (Courtesy of General Motors Corp.)

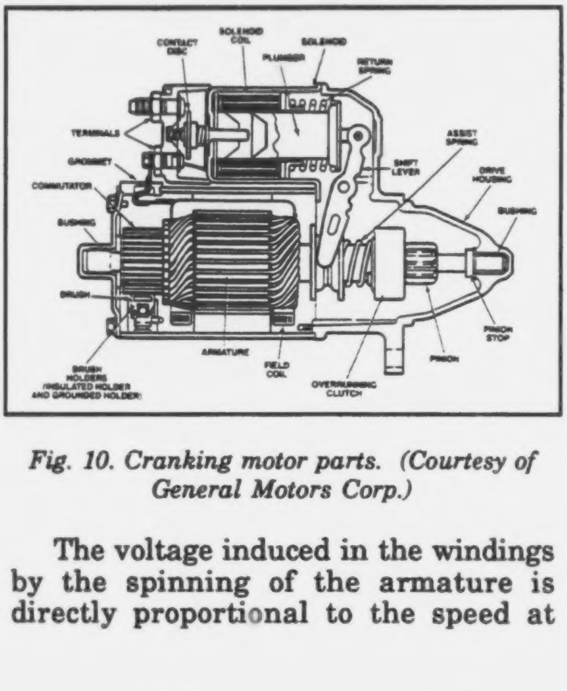

CONTACT DISC
SOLENOID COIL
SOLENOID
PLUNGER
RETURN SPRING
TERMINALS
GROMMET
COMMUTATOR
BUSHING
ASSIST SPRING
SHIFT LEVER
DRIVE HOUSING
BUSHING
BRUSH
PINION STOP
PINION
ARMATURE
FIELD COIL
OVERRUNNING CLUTCH
BRUSH HOLDERS (INSULATED HOLDER AND GROUNDED HOLDER)

Fig. 10. Cranking motor parts. (Courtesy of General Motors Corp.)

The voltage induced in the windings by the spinning of the armature is directly proportional to the speed at which the magnetic lines of force are cut. This means that the faster the armature spins, the more CEMF or induced voltage is generated to oppose the voltage from the battery. This also means that there is no CEMF or induced voltage when the armature is not moving, although the current from the battery is passing through it.

The amount of twisting force or torque is a function of the amount of current that passes through the motor. The maximum amount of current passes through the motor before it starts to turn, which is its point of maximum torque.

The starting unit for the starter motor is the solenoid (fig. 11). The *solenoid* is a coil formed to make an electromagnet with a movable core called the plunger. When the coil is energized, it pulls the plunger into the coil and holds it as long as power is applied.

Figure 12 shows the solenoid mounted to the top of the starter motor. The plunger is connected to the shift lever, which moves the armature to engage the pinion gears on the armature with the flywheel on the engine.

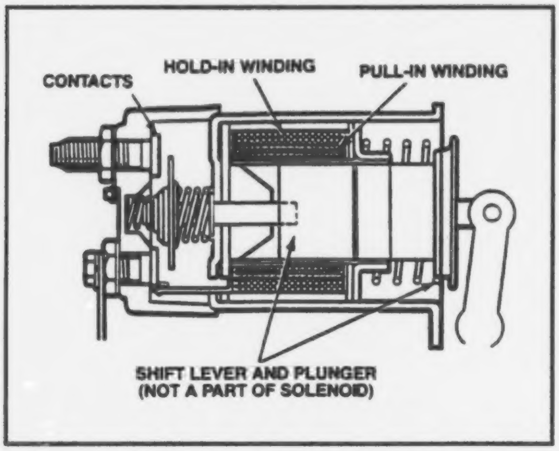

CONTACTS
HOLD-IN WINDING
PULL-IN WINDING
SHIFT LEVER AND PLUNGER
(NOT A PART OF SOLENOID)

Fig. 11. Solenoid. (Courtesy of General Motors Corp.)

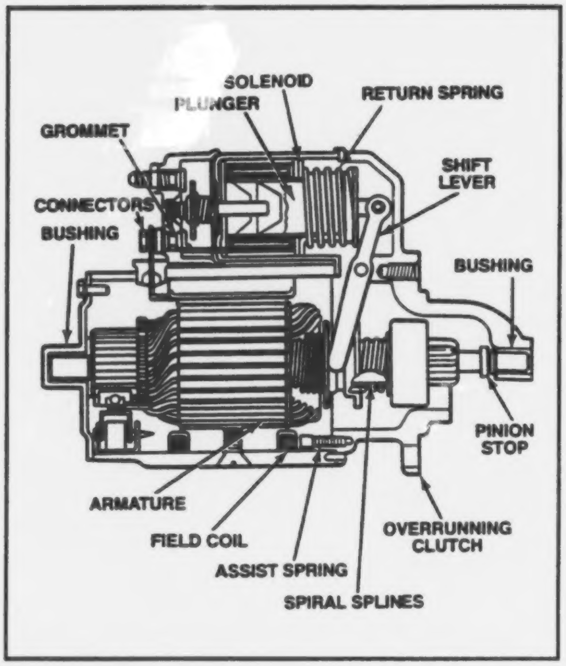

SOLENOID
PLUNGER
RETURN SPRING
GROMMET
SHIFT
LEVER
CONNECTORS
BUSHING
BUSHING
PINION
STOP
ARMATURE
FIELD COIL
OVERRUNNING
CLUTCH
ASSIST SPRING
SPIRAL SPLINES

Fig. 12. Solenoid attached to starter. (Courtesy of General Motors Corp.)

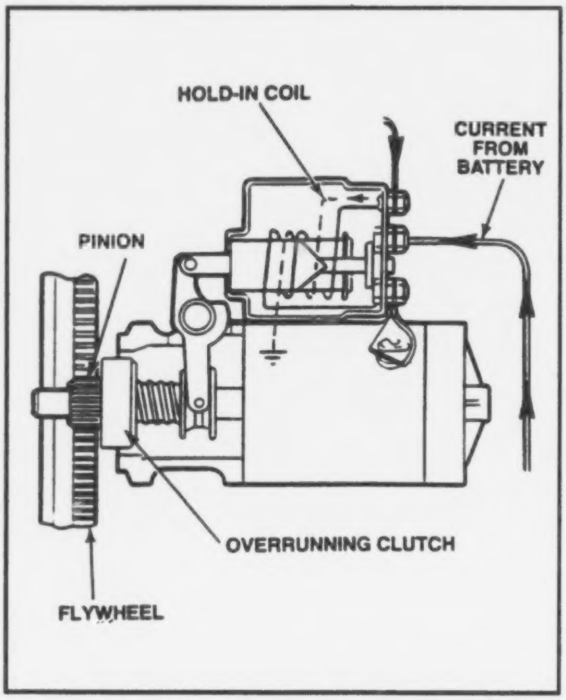

HOLD-IN COIL
CURRENT
FROM
BATTERY
PINION
OVERRUNNING CLUTCH
FLYWHEEL

Fig. 13. Pinion fully engaged and starter motor cranking. (Courtesy of General Motors Corp.)

When the plunger is fully into the coil, it makes contact with two conductors, which allows current to flow into the starter motor. Figure 13 shows how the plunger makes contact to supply current to the motor. Once current starts to flow into the motor, cranking takes place.

The solenoid has two windings, called the hold-in winding and the pull-in winding. Both windings have the same number of turns, but the pull-in winding has bigger diameter wire. When the start switch is closed, sending current to the solenoid, the current enters the solenoid at terminal S (fig. 14). The current travels through both the pull-in and hold-in windings, in parallel, creating the magnetism that pulls the plunger in. The current traveling through the pull-in winding travels to terminal M and then through the motor windings before returning to the battery. The current through the hold-in windings goes directly back to the battery.

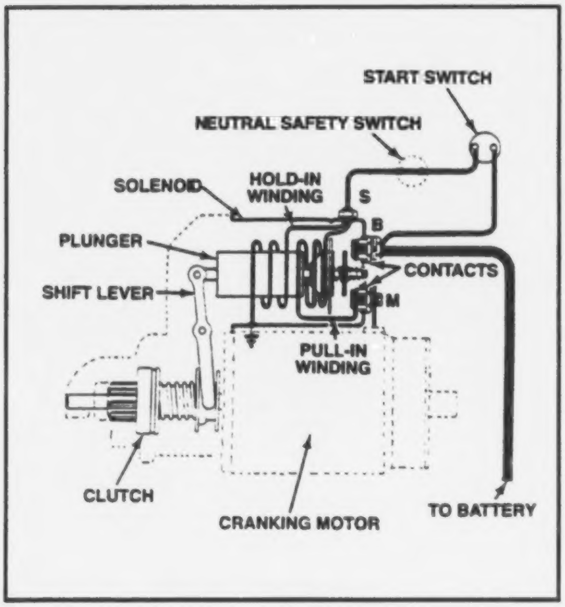


Fig. 14. Cranking motor circuit. (Courtesy of General Motors Corp.)

With the plunger pulled all the way in, the contact disk makes contact with terminals B and M, completing the circuit for current to flow directly from the battery through the motor windings and return to the battery. The plunger needs less magnetism to hold it in the coil than the magnetism needed to pull it in. With the plunger all the way in, the contact disk will be making contact with terminals B and M. The pull-in coil is now shorted and no longer provides any magnetic force. The hold-in coil provides the magnetism to hold the plunger in place during cranking. This design feature reduces the amount of current necessary to crank the motor and reduces the amount of heat buildup during cranking.

At the moment that current is first interrupted by the opening of the start switch, there is an induced current from the collapsing magnetic field in the motor that causes a momentary current to be fed back through terminal M and through the pull-in coil in the reverse direction. This reverse current generates a magnetic field that opposes the residual magnetic field in the hold-in coil, freeing the plunger to be pulled back immediately by the return spring.

Starter Motors with Different Designs

The starter motor shown in figure 15 has a smaller motor that is designed to run at a faster rate. The reduction gears reduce the speed of the pinion gear, which meshes with the flywheel. The plunger moves the gears and not the motor to engage the flywheel on this model. This motor will have the same final specifications on torque and speed delivered to the flywheel with less weight and more efficiency.

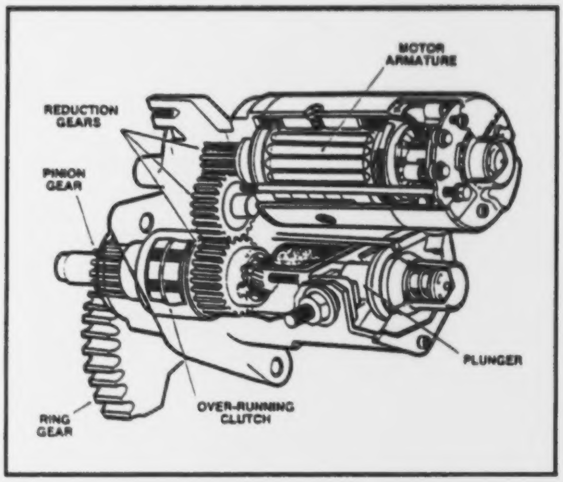

MOTOR ARMATURE
REDUCTION GEARS
PINION GEAR
PLUNGER
OVER-RUNNING CLUTCH
RING GEAR

Fig. 15. Gear reduction starter motor. (Courtesy of Toyota)

The starter shown in figure 16 uses permanent magnets instead of field coils in the motor. The motor is designed to run faster and uses a gear reduction system. Its weight is about half of what a conventional starter motor weighs, and it has a noticeably different sound when cranking.

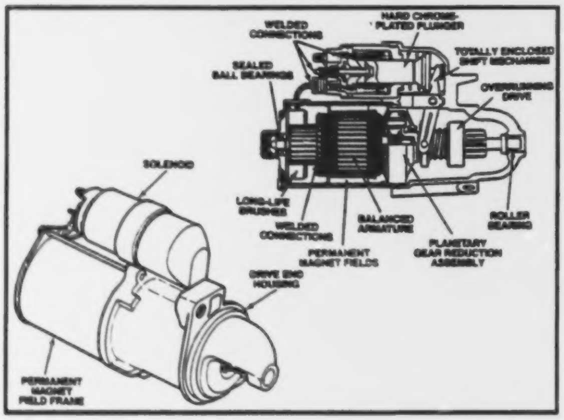

WELDED CONNECTIONS
HARD CHROME-PLATED PLUNGER
TOTALLY ENCLOSED SHIFT MECHANISM
SEALED BALL BEARINGS
OVERRUNNING DRIVE
SOLENOID
LONG-LIFE BRUSHES
WELDED CONNECTIONS
BALANCED ARMATURE
ROLLER BEARING
PERMANENT MAGNET FIELDS
PLANETARY GEAR REDUCTION ASSEMBLY
DRIVE END HOUSING
PERMANENT MAGNET FIELD FRAME

Fig. 16. Permanent magnet gear reduction cranking motor. (Courtesy of General Motors Corp.)

Troubleshooting the Starting System

A good visual inspection of the system is the best way to start troubleshooting the cranking system. The starter motor needs a lot of current, about 400 amp, to crank the engine. This high level of current requires clean tight connections to the starter motor. Poor connections in the control circuitry can also create problems. You should pay attention to the sounds and behavior of the engine and starting motor during the cranking process. If you hear the solenoid kick in and the motor does not start cranking, then obviously the control circuitry is working and you will need to look at the circuit taking current to the motor. It is also important to have a good idea where everything is on the car and where all the potential problems could be (see fig. 17).

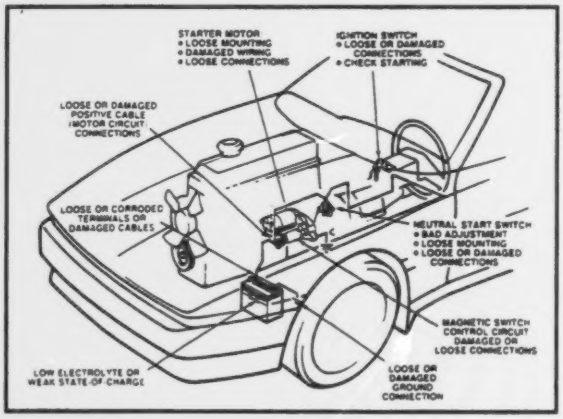

STARTER MOTOR
• LOOSE MOUNTING
• DAMAGED WIRING
• LOOSE CONNECTIONS
IGNITION SWITCH
• LOOSE OR DAMAGED CONNECTIONS
• CHECK STARTING
LOOSE OR DAMAGED POSITIVE CABLE /MOTOR CIRCUIT CONNECTIONS
LOOSE OR CORRODED TERMINALS OR DAMAGED CABLES
NEUTRAL START SWITCH
• BAD ADJUSTMENT
• LOOSE MOUNTING
• LOOSE OR DAMAGED CONNECTIONS
MAGNETIC SWITCH CONTROL CIRCUIT DAMAGED OR LOOSE CONNECTIONS
LOW ELECTROLYTE OR WEAK STATE-OF-CHARGE
LOOSE OR DAMAGED GROUND CONNECTION

Fig. 17. Points to check when troubleshooting a cranking system. (Courtesy of Toyota)

You can use your DVOM to check for excessive resistance due to a poor or dirty connection. This is called voltage drop testing (fig. 18).

If you look at each connection as a potential resistor that will drop some of the voltage when current is flowing, then you can test for these conditions. Fgure 18 shows some of the maximum voltage drops that would be allowable during the cranking operation. When running these tests, it is a good idea to disable the ignition so the car does not start.

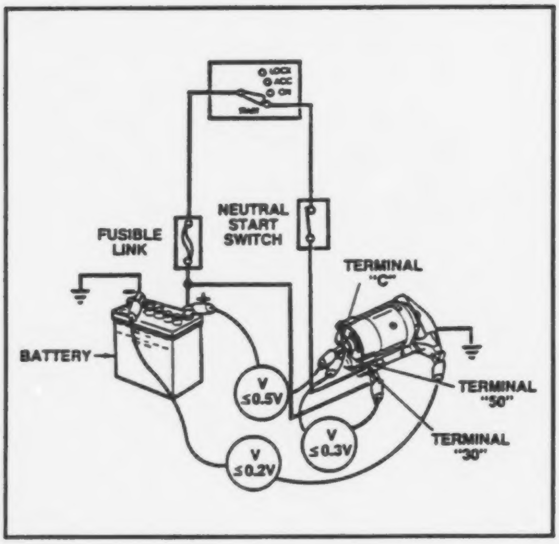

LOCK
ACC
ON
START
FUSIBLE LINK
NEUTRAL START SWITCH
TERMINAL "C"
BATTERY
V ≤0.5V
V ≤0.3V
V ≤0.2V
TERMINAL "50"
TERMINAL "30"

Fig. 18. Voltage drop test: motor circuit. (Courtesy of Toyota)

During cranking, there should be less than 0.5 volt drop from the positive terminal of the battery and the terminal on the solenoid. There should be less than 0.3 volt drop between the terminal on the solenoid and the main power terminal going into the motor.

Figure 19 shows the maximum voltage drops that are acceptable for the starting control circuit. There should be no significant voltage drop across any of the relays, switches, or fuses. If there is more than 1.5 volt drop from the positive terminal of the batter to terminal 50 on the motor, then there is a poor connection somewhere in that circuit.

Starter Motor Bench Tests

If the initial voltage drop tests indicate a problem with the starter motor, it should be removed from the car and bench-tested. Do not continue to run current through the starter motor for more than a few seconds since it will heat up and may become permanently damaged.

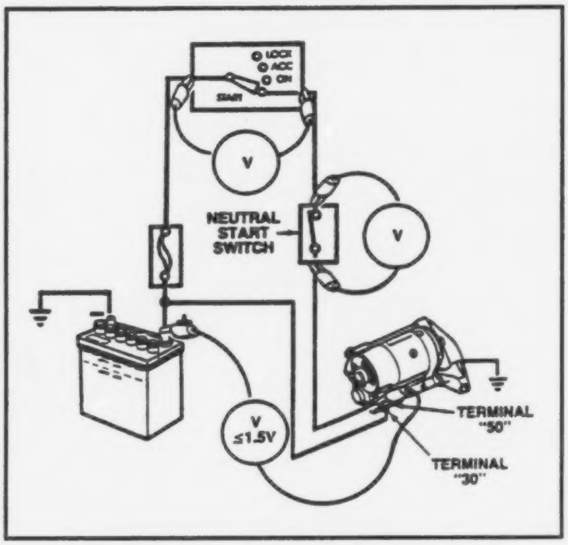

LOCK
ACC
ON
START
V
NEUTRAL START SWITCH
V
V ≤1.5V
TERMINAL "50"
TERMINAL "30"

Fig. 19. Voltage drop test: control circuit. (Courtesy of Toyota)

To test the ability of the solenoid to operate the plunger and pull in the motor, connect the battery's negative terminal to the case (fig. 20), and momentarily connect the positive terminal to the solenoid input. This should cause the plunger to move, and you should see the pinion gear move out. If the unit does not operate properly, then it should be disassembled for further inspection or replaced.

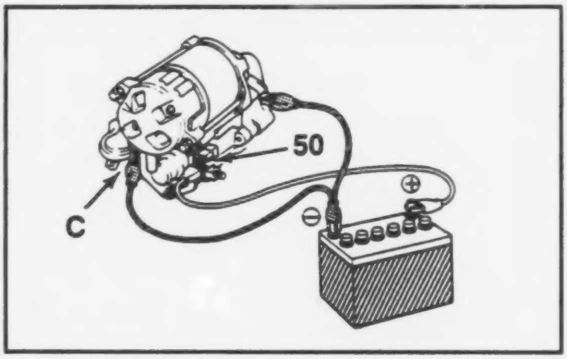


Fig. 20. Pull-in test. (Courtesy of Toyota)

The next test of the starter motor is to connect it to the battery in series with an ammeter so it will run with the solenoid pulled in. Connect it as shown in figure 21. The motor should run smoothly with the pinion gear out. Refer to the appropriate service manual for the specified current for this test on this motor.

When the starter motor or the solenoid is found to be defective, the unit should be disassembled. You should wear safety glasses when disassembling or assembling the motor and solenoid. With the unit disassembled, inspect the brushes and the brush holders. The brush should not bind in the holder, and if there is any wear, replace the brushes. If the commutator is rough or worn, it can be turned down. Only turn it down far enough to clean it up. Avoid taking too much metal off the commutator.

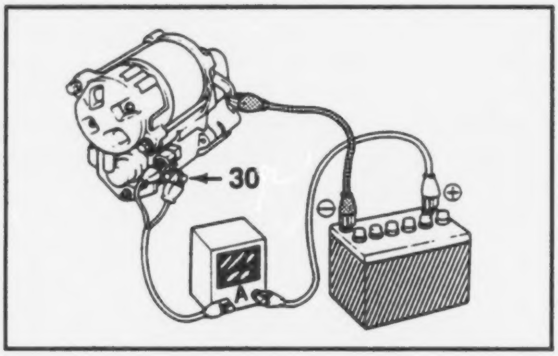


Fig. 21. No-load performance test. (Courtesy of Toyota.)

Exercise

1. What is the maximum acceptable voltage drop from the solenoid input terminal to the motor input terminal on a starter motor?
2. What will happen if the contact disk does not make contact with the terminals B and M?
3. How would the starter motor behave if the hold-in coil on the solenoid was open?
4. Examine figure 22, and determine which two terminals (Bat, S, M) would need to be shorted to crank the engine without operating the start switch.
5. The typical resistance of the hold-in coil is 0.72 Ω, and the pull-in coil is 0.15 Ω. Examine the circuit in figure 23, and write the expected resistance values for the circuit between the following terminals. There are no external wires connected to terminals S, B, and M.
   a. S to G
   b. S to B
   c. S to M
   d. B to M

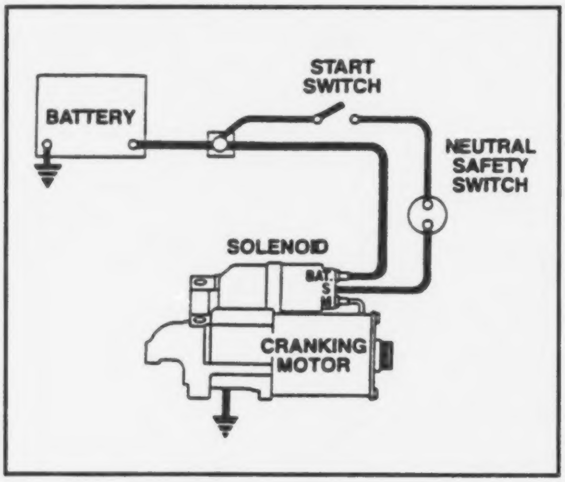


Fig. 22. Basic starting system circuit. (Courtesy of General Motors Corp.)

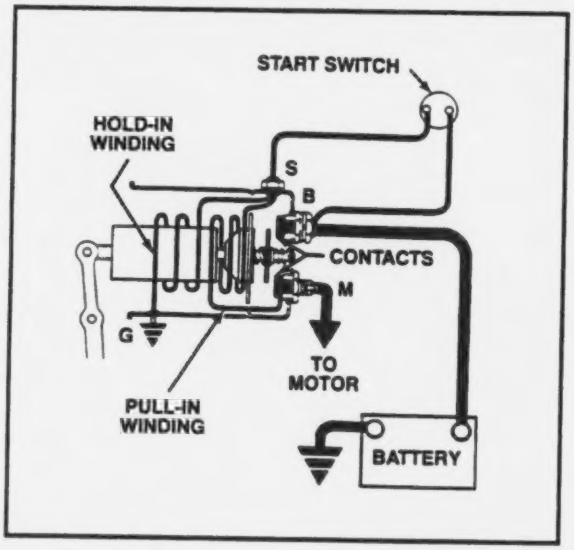

START SWITCH
HOLD-IN WINDING
S
B
CONTACTS
M
G
TO MOTOR
PULL-IN WINDING
BATTERY

Fig. 23. Solenoid circuit. (Courtesy of General Motors Corp.)

D-3 The Cranking System

Laboratory Experiment

Essential Elements: (gg)(1–4)

Objective

In this lab, the student will examine the problem caused by poor connections.

Equipment

1	6-volt voltage source (batteries and battery holder)
1	220 Ω resistor
1	variable resistor (10 kΩ pot)
1	DVOM

Procedure

A poor connection acts like a resistor to the current flow. The added resistance can be measured as a voltage drop. The amount of the voltage drop will depend on the amount of current and the amount of resistance. We will connect a variable resistor or potentiometer in series with a circuit from the voltage source to an LED and current-limiting resistor. The variable resistor will represent a bad connection.

1. Use your jumpers to connect a 220 Ω resistor in series with the LED, and connect this in series with the voltage source. Change the polarity at the voltage source if the LED does not light. Use your DVOM to measure the voltages at all nodes. Record all of the voltages that you have measured.

2. Now connect the pot in series with the LED and current-limiting resistor (220 Ω), by connecting to the outside terminal and the center terminal.

3. Adjust the pot to about the midpoint, and use your DVOM to measure the voltages at all nodes. Record all your voltage measurements.

4. Look at your voltage measurements, and notice that the voltage drop across the pot is much larger than the voltage drop across your 220 Ω resistor. If the pot is a 10 kΩ, the midpoint on it will have added 5 kΩ of resistance. The voltage drop will increase or decrease with the resistance.

5. Adjust the pot until the LED is just barely on, and remeasure the voltage drop across the pot. Record this measurement. Next, adjust the pot so the LED has a strong light, and measure the voltage drop across the pot. Record this measurement.

Notice how the voltage drop increases as the light decreases. On the starter motor circuit, as the resistance of a bad connection increases, the current to the motor and the ability of the motor to work will decrease.

Unit

E

Body Electrical Systems

E-1 Body Lights, Switches, and Related Systems
E-2 Instrument Panel
E-3 Vehicle Restraint Systems

E-1

Body Lights, Switches, and Related Systems

Essential Elements: **(gg)(1, 2, and 4)**

Unit Objectives:

After completing this instructional unit, you will be able to explain the operations of:

- *lights and switches system and related systems on a typical car*
- *automotive instrument panel*
- *active and passive restraint systems*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain the procedures for troubleshooting problems in the headlight and taillight circuits*
- *explain the procedures for using the troubleshooting plan*

The Automobile

The typical automobile is composed of many different electrical and electronic systems. These systems all obtain their power from the battery and alternator systems. The important part of these voltage source systems is the wiring and control systems that operate the various lights and equipment.

When one of these systems fails either in part or the whole system goes down, a systematic method of troubleshooting will decrease the time it takes to find the problem and put the car back on the road.

The first step in any troubleshooting problem is to understand the system and know where its key components are located. The schematic drawings for the system and automobile are very important tools in obtaining this understanding.

Once you understand how the system works and have some idea where each of the key parts to the system is located, then the next step is to follow a good troubleshooting plan. A good troubleshooting plan was first presented to you in Assignment C-5. We have included the highlights of the plan in the following.

The Troubleshooting Plan

1. *Determine the specific complaint.*

This part of the plan involves asking questions of the driver or simply trying to quickly obtain as much information on the problem as possible under the circumstances in which you work.

2. *Demonstrate the problem.*
   Try to make the problem happen in your presence. Some car owners find that an intermittent problem does not show up when they bring the car in for service. One reason can be that the technician operates the car differently than the owner. Try to imitate what the owner does, or have the owner drive you around to demonstrate the problem.

3. *Stop and think!*
   Take a moment to consider all of the symptoms and all of what you know about the car and the problem. Stopping for a moment can help you avoid wasting a lot of time on unproductive troubleshooting practices.

4. *Plan additional tests.*
   Determine what additional information you need, and plan how you are going to get that information. Taking a lot of voltage measurements at random is a waste of time.

5. *Locate the problem.*
   Try to avoid replacing good components. Make enough tests to be sure of the problem or bad component.

6. *Make the repair.*
   Doing a quality job is important for this step.

7. *Test the repaired vehicle.*
   You should always test the car after you have finished repairing it.

Voltage Tests

When conducting voltage tests on a failed system, you should record your results, and you will often need to take readings under all conditions. For example, in figure 1, "all conditions" could mean in all ignition switch positions.

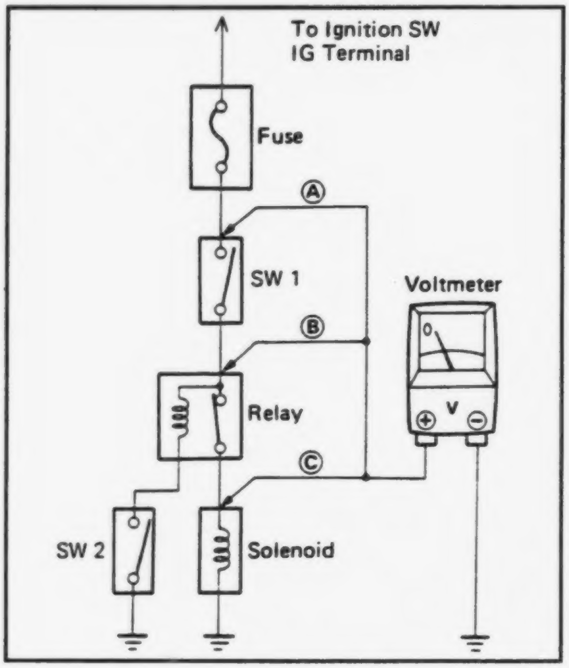


Fig. 1. Voltage test.
(Courtesy of Toyota)

Notice, in figure 1, that the meter has its negative lead connected to ground. This is usually done to speed up all tests. All voltage measurements are then taken with respect to ground. If you need a voltage drop measurement across a component, just find the difference between the voltage measurements on each side of the component for the voltage drop value.

In figure 1, if the supply voltage from the battery is 12.6 volts, then the voltage at point "A" should be 12.6

volts. With switch "SW 1" open, the voltage measured at points "B" and "C" should be zero.

The relay (fig. 1) appears to be normally closed, so closing switch "SW 1" should put current to the solenoid at the bottom. If there is any significant voltage drop across the closed switches and relays, they should be replaced.

Checking for Continuity or Resistance

When making resistance checks, the circuit under test should not have any voltage on it. Any voltage not supplied by the meter will make a resistance check useless and may damage the meter. When testing a switch, simply connect the leads to each side of the component (fig. 2).

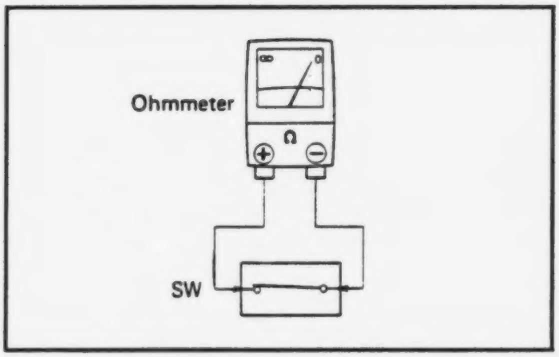

Ohmmeter
Ω
SW

Fig. 2. Continuity and resistance test. (Courtesy of Toyota)

If you are testing diodes for continuity or to see if they are still good, use the diode function on your DVOM. The normal resistance function on your DVOM does not provide enough voltage to overcome the 0.7 volt junction voltage requirement. With your DVOM in the diode test mode, test the diodes from both directions (fig. 3).

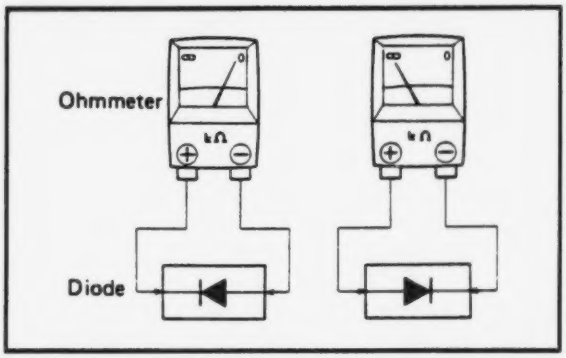

Ohmmeter
kΩ
Diode

Fig. 3. Reverse the leads when checking diodes. (Courtesy of Toyota)

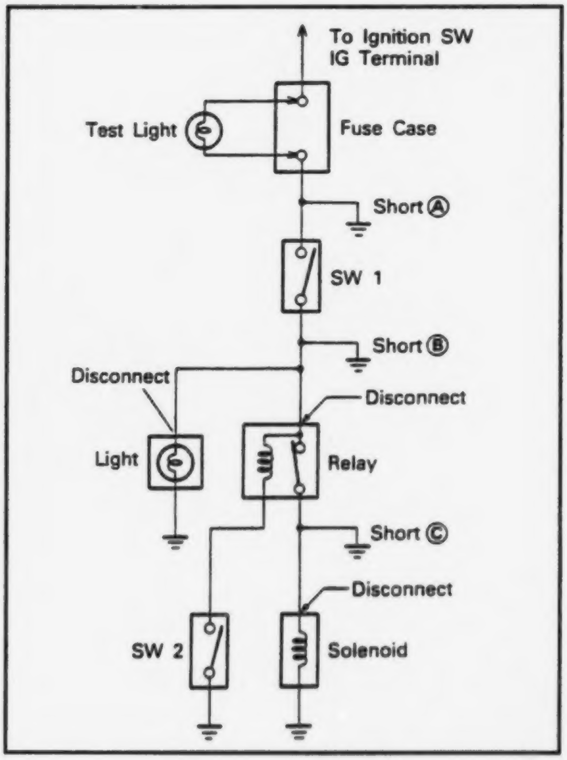

To Ignition SW
IG Terminal
Test Light
Fuse Case
Short Ⓐ
SW 1
Short Ⓑ
Disconnect
Disconnect
Light
Relay
Short Ⓒ
Disconnect
SW 2
Solenoid

Fig. 4. Locating a short. (Courtesy of Toyota)

Locating a Short Circuit

If the problem is a blown fuse, it often can be a short circuit. The first

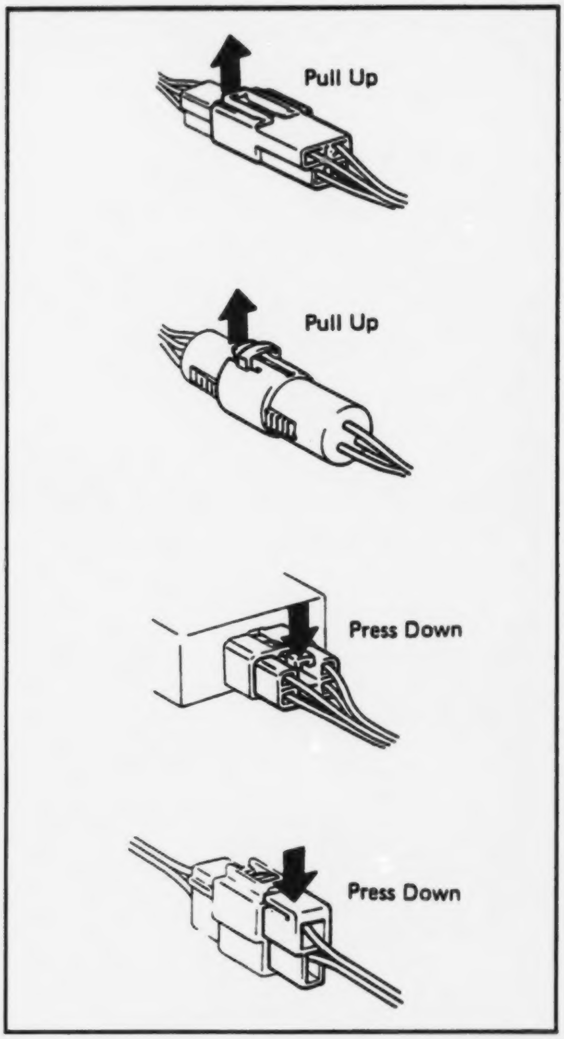


Fig. 5. Check to see the type of connector you are disconnecting before pulling it apart. (Courtesy of Toyota)

step in locating this problem is to remove the blown fuse and disconnect all of the loads on this fuse. Wire in a test light in the fuse socket (fig. 4). If there is any current drawn from this point by the short, the light will be on. Now reconnect each plug or load, one at a time, watching the test light until it lights. Once you know in what area the problem is, sometimes gently shaking the wire can cause the short to go on and off. This can help you find the specific point where the short is.

When you disconnect the plugs and connectors, you should look at them first to see what type they are and how they come apart. Figure 5 shows some of the more common types and how they can be pulled apart.

Headlight System

Figure 6 shows the headlight system for a 1990 Toyota Supra. This car has retractable headlights and a theft-deterrent system. The box on the right side of the drawing, about halfway up, houses the integration relay No. 2, which controls the retractable headlights. The letter *E* with a circle around it identifies the plug for that module in the service literature.

A 30-amp fusible link protects the integration relay No. 2 and the retract motors. There is also a circuit breaker after each retractable motor. Each of the headlights has its own 15-amp fuse, which is unusual. Most cars have one fuse for both headlights. The box on the left is the "COMB SW," or combination switch that controls the light system.

When troubleshooting this system, it is important to look for a point which when failed would cause the particular problem. If there is a string of components that could cause the problem, then testing at the halfway point would be appropriate.

Self-Test 1

Try to figure out the best answer to each question before reading the answer. Consider all possibilities and what tests might be needed.

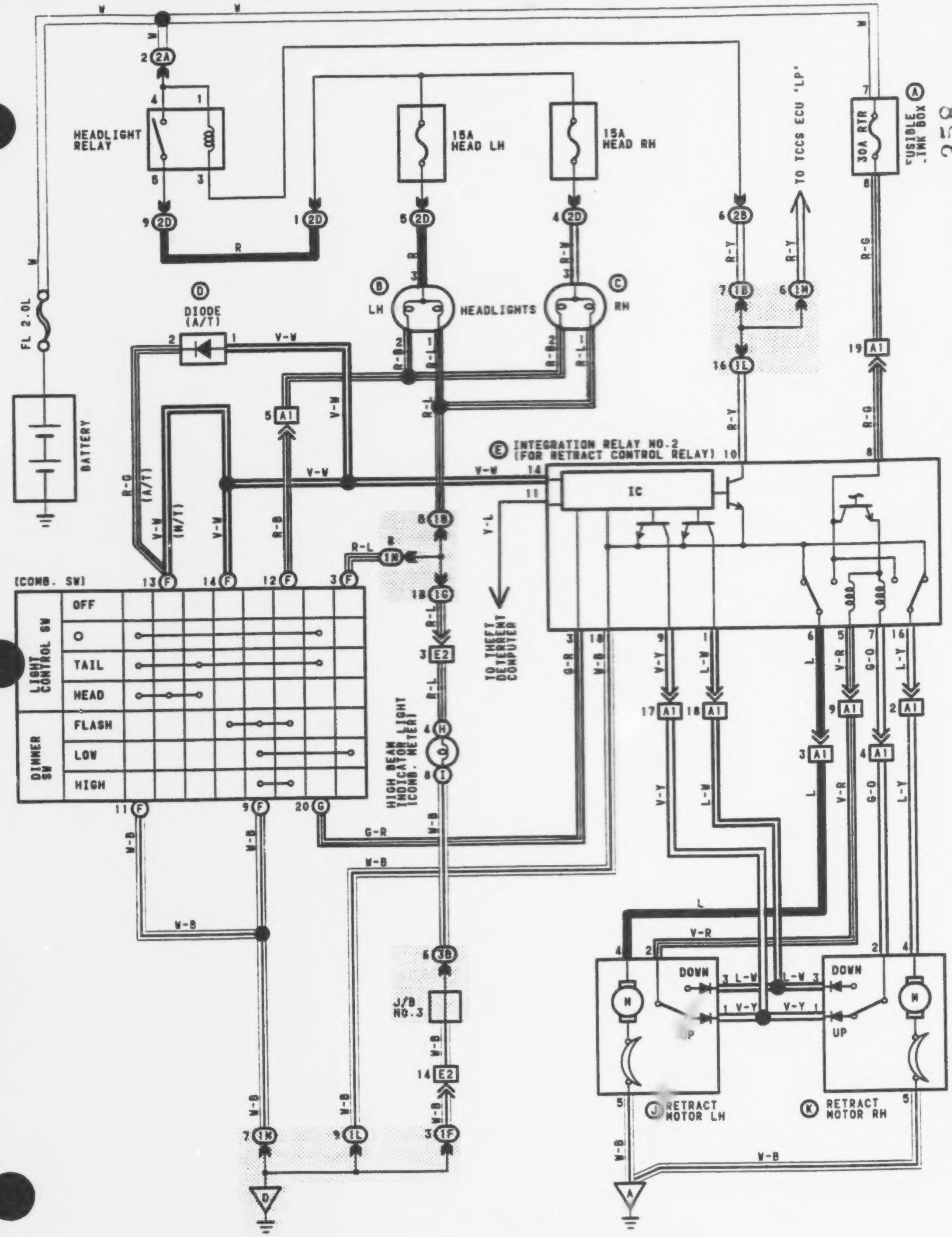

HEADLIGHT RELAY
15A HEAD LH
15A HEAD RH
TO TCCS ECU 'LP'
30A RTR
FUSIBLE LINK BOX Ⓐ
FL 2.0L
BATTERY
Ⓓ DIODE (A/T)
Ⓑ LH
HEADLIGHTS
Ⓒ RH
Ⓔ INTEGRATION RELAY NO.2 (FOR RETRACT CONTROL RELAY)
IC
[COMB. SW]
LIGHT CONTROL SW
OFF
O
TAIL
HEAD
DIMMER SW
FLASH
LOW
HIGH
R-G (A/T)
V-W (M/T)
V-W
R-B
R-L
Y-L
G-R
W-B
R
R-Y
R-G
V-Y
L-W
L
V-R
G-O
L-Y
W
TO THEFT DETERRENT COMPUTER
HIGH BEAM INDICATOR LIGHT (COMB. METER)
J/B NO.3
DOWN
UP
Ⓙ RETRACT MOTOR LH
Ⓚ RETRACT MOTOR RH
M

Fig. 6. Headlight schematic. (Courtesy of Toyota)

1. If both headlights failed, which component would be the most likely cause of the problem?

   Answer: The headlight relay is common to both headlights, therefore it would be the first item to look at. An open conductor between the relay and the lights could also be the problem. The circuit that controls the relay, including the Integration Relay No. 2 box, is another strong possibility. You should start by using your DVOM to test the relay. If there is voltage to and from the coil in the relay (pins 1 and 3), then check for a voltage on pin 5 of the relay. If there is battery voltage on pin 5, then there is a break somewhere in the conductor to the headlights.

   Battery voltage on pin 3 of the headlight relay would mean that the Integration Relay No. 2 was probably not grounding the circuit to turn on the relay.

2. If the RETRACT MOTOR RH failed to open, where should you start testing?

   Answer: With the controls set to open the retractable headlights, test for a voltage on pin 4 of the retract unit. A lack of voltage there would indicate a problem in the Integration Relay No. 2. If the voltage was there, then the problem could be either in the circuit breaker, the motor, or a loose ground. Checking pin 5 would help prove or eliminate the ground as a possibility. If pin 5 had battery voltage on it, then the ground is probably at fault. No voltage on pin 5 means the problem is inside the retract unit, either the circuit breaker or the motor.

Turn Signal and Hazard Warning Lights

The turn signal system on a car will activate either the left or right signal lights and cause them to flash. The hazard system flashes all of the signal lights. The signal lights are shown at the bottom of figure 7, and the indicator lights are to the right, enclosed in the box.

This system is relatively simple with no integrated circuits or computer control. There is a separate switch for the hazard system and the turn signal system. A 15-amp fuse protects the hazard system and the horn, and a separate 7.5-amp fuse protects the turn signal system. Notice that the common points between the two systems are the flasher relay and the lights.

Self-Test 2

1. You are asked to troubleshoot a car with the complaint that the left turn signal blows the 7.5 amp fuse. How should you proceed?

   Answer: Blowing a fuse like this normally means a short to ground somewhere in the system. The path from the 7.5-amp fuse goes into the hazard switch at pin 9 and supplies current to the turn signal flasher relay from pin 7. The turn signal flasher receives the current at pin 3 and sends the flashing current out pin 1. The turn signal switch receives the flashing current in pin 1, and for the left signals it sends the current out pin 5.

   First, remove the blown 7.5-amp fuse and remove the 15-amp fuse from the hazard system since they are tied together and you may contact a hot wire. Next use your

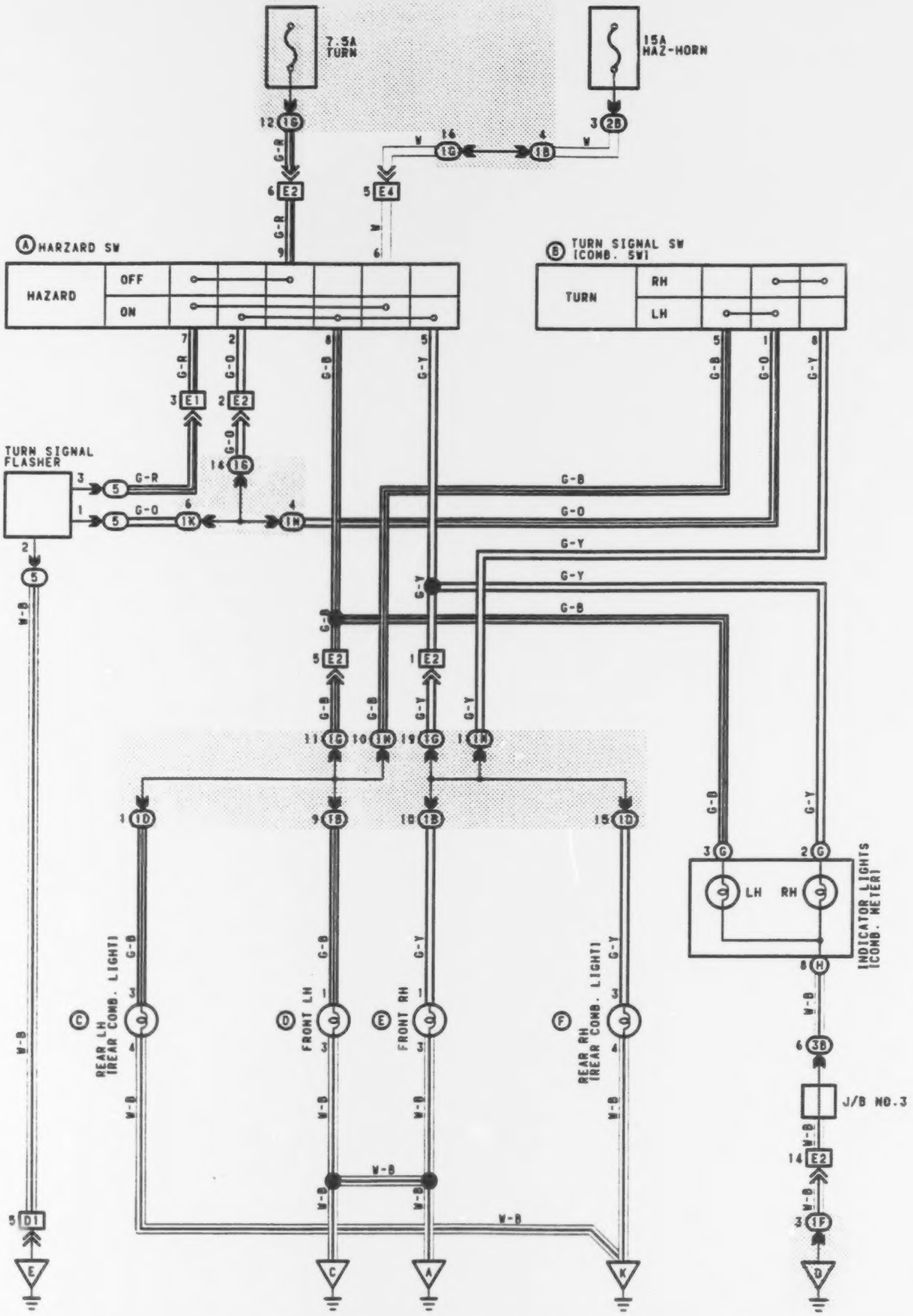

7.5A TURN
15A HAZ-HORN
Ⓐ HARZARD SW
HAZARD
OFF
ON
Ⓑ TURN SIGNAL SW (COMB. SW)
TURN
RH
LH
TURN SIGNAL FLASHER
G-R
G-O
G-B
G-Y
W
W-B
E1
E2
E4
1G
1B
2B
1K
1M
1D
1F
3B
D1
INDICATOR LIGHTS (COMB. METER)
LH
RH
Ⓒ REAR LH (REAR COMB. LIGHT)
Ⓓ FRONT LH
Ⓔ FRONT RH
Ⓕ REAR RH (REAR COMB. LIGHT)
J/B NO.3
E
C
A
K
D

Fig. 7. Turn signal and hazard warning lights schematic. (Courtesy of Toyota)

DVOM on the resistance function, testing for low resistance that will indicate a short. Start your test at the halfway point, which in this case would be the turn signal flasher relay. Pull the relay, and test for a low resistance to ground at pins 1 and 3. If pin 3 showed a resistance of 5 Ω, we would know that the short was prior to this point. Next check at the halfway point figured from the fuse to pin 3 on the relay. This would be about pin 7 on the hazard switch. Since you need to open the wire, the appropriate point would be the plug at E1. Open this plug, and test for a low resistance on both sides of the plug. A low resistance on the plug side going to the relay would lock in that piece of wire as the problem. The next step is to visually check that piece of wire for the problem.

As you become familiar with each car that you work on, you will learn where you can easily make tests and this should influence your decision on where you find your halfway point.

Stoplights

The stoplights shown in figure 8 have a light failure sensor which will turn on the rear lights warning light on the dash when it senses an open in the stoplight circuit. The 20-amp fuse at the top left corner of the drawing supplies current continuously. There are no switches prior to that fuse. The 7.5-amp fuse is switched through the ignition switch.

The light failure sensor senses an open light bulb by the voltage drop difference across the resistor from pin 7 of the light failure sensor module and where the op-amp (triangle) is connected. This voltage drop will change with the amount of current passing through the circuit. A burnt light bulb will result in a different voltage into the op-amp, resulting in turning on the transistor, which will allow current from pin 3 to pin 9 of the sensor module.

Self-Test 3

1. A customer came in and stated that his rear light warning light had not worked when he had lost one of his stoplights. The stoplights are all working now. What procedure would you take in investigating this problem?

   Answer: The first step would be to confirm the problem by removing one of the stoplights and checking the warning light. If the warning light fails to light, then check the 7.5-amp fuse that supplies the warning light.

   If the 7.5 amp fuse is good, then you should start checking with your DVOM. The halfway point would be the light failure sensor module. Check pins 2 and 3 for voltage. If they have battery voltage on them, then check pin 9 for voltage. Since this is a ground connection, it should read 0 volts. If this has battery voltage on it, then there is a problem with the ground, or the wire going to the ground connection is open. If all pins on the light failure sensor check out as they should, then the sensor module itself would need to be replaced.

Exercise

1. List the seven steps in the troubleshooting plan.

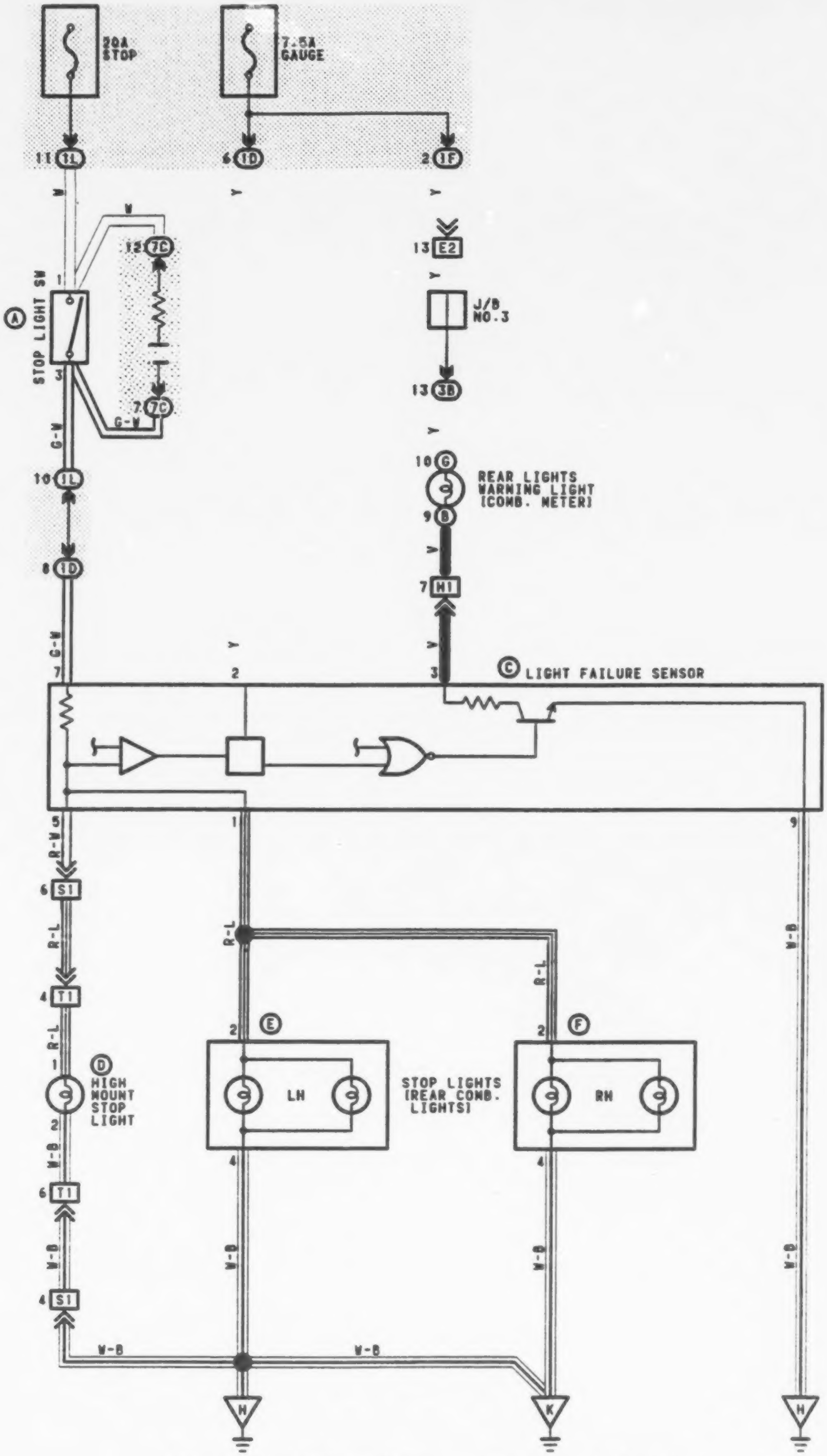

20A STOP
7.5A GAUGE
11 1L
6 1D
2 1F
W
Y
Y
W
12 7C
13 E2
Y
1
Ⓐ STOP LIGHT SW
J/B NO.3
3
7 7C
G-W
13 3B
G-W
Y
10 G
REAR LIGHTS WARNING LIGHT [COMB. METER]
9 B
10 1L
Y
8 1D
7 H1
G-W
Y
Y
7
2
3
Ⓒ LIGHT FAILURE SENSOR
5
1
9
R-W
6 S1
R-L
R-L
R-L
W-B
4 T1
R-L
2 Ⓔ
2 Ⓕ
1
Ⓓ HIGH MOUNT STOP LIGHT
LH
STOP LIGHTS [REAR COMB. LIGHTS]
RH
2
4
4
W-B
6 T1
W-B
W-B
W-B
W-B
4 S1
W-B
W-B
H
K
H

Fig. 8. Stop lights schematic. (Courtesy of Toyota)

2. When taking voltage measurements to ground, you find that the voltage on one side of a 1 kΩ resistor is 12 volts and on the other side is 10.5 volts. How much current is passing through this resistor?

3. A technician was using his DVOM to measure the resistance of a group of resistors. Upon completion of this, the technician immediately started testing a group of diodes. The diodes, although new, all appeared to be open. Why do the diodes all appear to be open?

4. What type of problem does a blown fuse usually indicate?

5. A customer tells you that his backup lights do not work. You obtain the schematic (fig. 9) and examine it. Then you put the car into reverse and use your DVOM to test for voltage to ground at 3B. The voltage at 3B is the battery voltage. You then test at the bottom of the switch at the point B and C. You find the voltage is zero at this point. You take another reading at point A and C and find battery voltage. What has probably failed and needs to repaired or replaced?

6. A new customer comes in and tells you that her backup lights do not work and the gauge fuse has blown. You remove the blown fuse, put the car in neutral, and use your DVOM to measure the resistance on the bottom side of the fuse socket. The reading is only a few ohms of resistance, indicating a short. When you look at the schematic (fig. 9), you notice that the current travels to a junction box (3B) after leaving the fuse block and then to the backup light switch. After the backup light switch, there is a long run of wire to the backup lights. Where should you test for the short next?

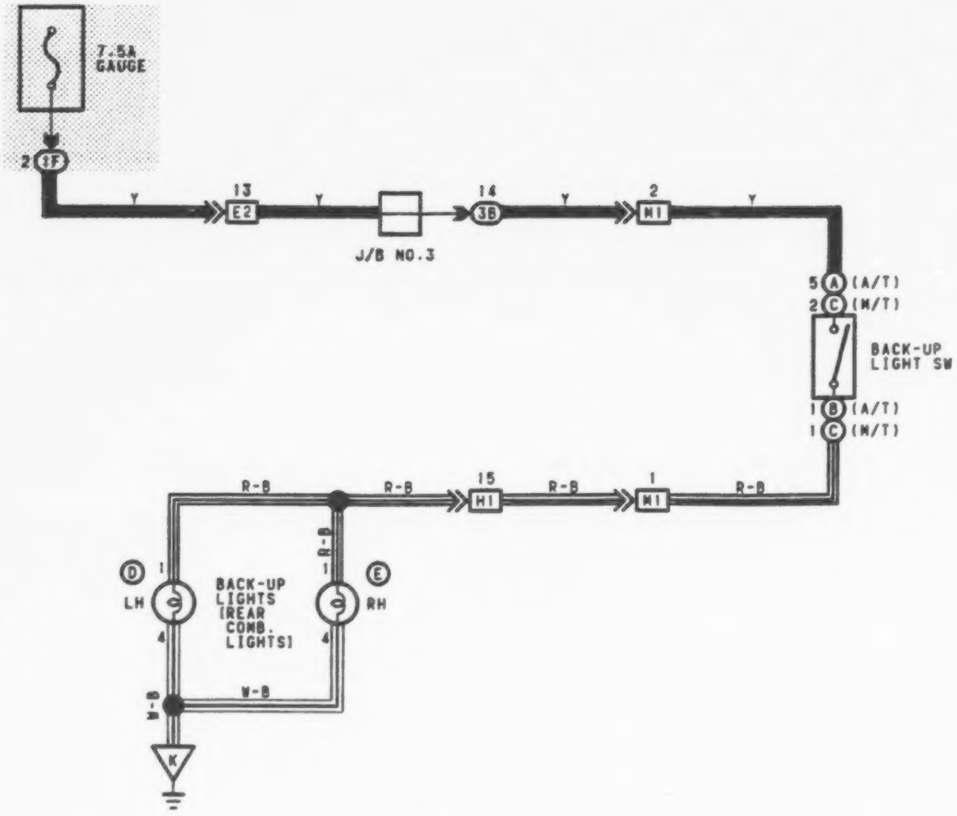
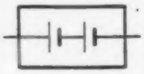
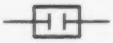

7.5A GAUGE
2
1F
Y
13
E2
Y
J/B NO.3
14
3B
Y
2
W1
Y
5 A (A/T)
2 C (M/T)
BACK-UP LIGHT SW
1 B (A/T)
1 C (M/T)
R-B
15
H1
R-B
1
W1
R-B
R-B
R-B
D
1
LH
4
BACK-UP LIGHTS [REAR COMB. LIGHTS]
E
1
RH
4
W-B
W-B
K

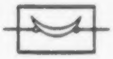
Fig. 9. Backup lights schematic. (Courtesy of Toyota)



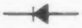
BATTERY
Stores chemical energy and converts it to electrical energy. Provides DC current for the auto's various electrical circuits.



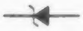
CAPACITOR
A small holding unit for temporary storage of electrical voltage.



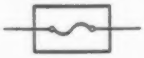
CIRCUIT BREAKER
A reusable fuse, a circuit breaker will heat and open if too much current flows through it. Some units automatically reset when cool; others must be manually reset.



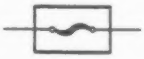
DIODE
A semiconductor that allows current flow in only one direction.



DIODE, ZENER
A diode that allows current flow only up to a specific voltage. Above that potential, it passes the excess voltage. This acts as a simple voltage regulator.

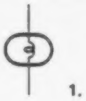


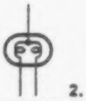
FUSE
A thin metal strip that burns through when too much current flows through it, thereby stopping current flow and protecting the circuit.



FUSIBLE LINK
A heavy-gauge wire placed in high amperage circuits that burns through on overloads, thereby protecting the circuit.

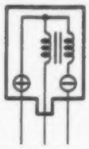
GROUND
The point at which wiring attaches to the body, thereby providing a return path for an electrical circuit; without a ground, current cannot flow.



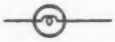


HEADLIGHTS
Current flow causes a headlight filament to heat up and emit light. A headlight may have either a single (1) or a double (2) filament.

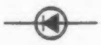
1. SINGLE FILAMENT
2. DOUBLE FILAMENT



IGNITION COIL
Converts electric low-voltage DC current into high-voltage ignition current for firing the spark plugs.

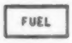


LIGHT
Current flow through a filament causes the filament to heat up and emit light.



LED (LIGHT-EMITTING DIODE)
Upon current flow, these diodes emit light without producing the heat of a comparable light.

METER, ANALOG
Current flow activates a magnetic coil that causes a needle to move, thereby providing a relative display against a background calibration.



METER, DIGITAL
Current flow activates one or many LEDs, LCDs, or fluorescent displays, which provide a relative digital display.

Fig. 10. Glossary of terms and symbols.

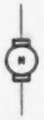
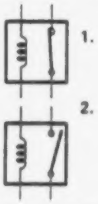
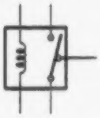
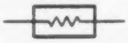
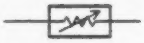
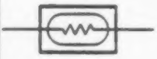
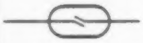
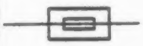
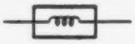
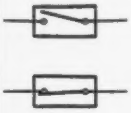
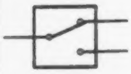
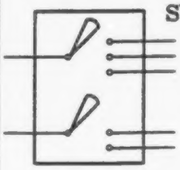
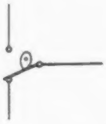
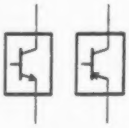
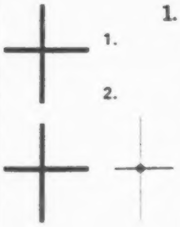
	**MOTOR** A power unit that converts electrical energy into mechanical energy, especially rotary motion.
	**RELAY** Opens and close, thereby stopping (1) or allowing (2) current to flow. 1. Normally Closed 2. Normally Open
	**RELAY, DOUBLE THROW** A relay that passes current through one set of contacts or the other.
	**RESISTOR** An electrical component with a fixed resistance, placed in a circuit to reduce voltage to a specific value.
	**RESISTOR, VARIABLE** A controllable resistor with a variable rate of resistance. Also a potentiometer or rheostat.
	**SENSOR (THERMISTOR)** A resistor that varies its resistance with temperature.
	**SENSOR, ANALOG SPEED** Uses magnetic impulses to open and close a switch to create a signal for activation of other components.
	**SHORT PIN** Used to provide an unbroken connection within a junction block.
	**SOLENOID** An electromagnetic coil that forms a magnetic field when current flows, to move a plunger, etc.
	**SWITCH, MANUAL** Opens and closes circuits, thereby stopping (1) or allowing (2) current flow. 1. Normally Open 2. Normally Closed
	**SWITCH, DOUBLE THROW** A switch that continuously passes current through one set of contacts or the other.
	**SWITCH, IGNITION** A key-operated switch with several positions that allow various circuits, particularly the primary ignition circuit, to become operational.
	**SWITCH, WIPER PARK** Automatically returns wipers to the stop position when the wiper switch is turned off.
	**TRANSISTOR** A solid-state device typically used as an electronic relay, stops or passes current depending on the applied voltage at "base."
	**WIRES** 1. Not Connected Wires are always drawn as straight lines on wiring diagrams. Crossed wires (1) without a black dot at the junction are not joined. Crossed wires (2) with a black dot at the junction are spliced (joined) connections.

Fig. 10. Glossary of terms and symbols

E-1 Body Lights, Switches, and Related Systems

Laboratory Experiment

Essential Elements: **(gg) (1, 2, and 4)**

Objective

In this lab, the student will examine and understand the problem of opens and shorts.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 220 Ω resistor
1 light-emitting diode
1 variable resistor (10 kΩ pot)
1 DVOM

Procedure

1. Obtain a blank sheet of paper, and draw a schematic showing your 6-volt source in series with a 47 Ω resistor feeding a load that consists of a 220 Ω current-limiting resistor in series with the LED. Assume that the LED will draw 15 mA of current, and calculate the voltages to ground at all nodes. A *node* is a point where a component is connected or two or more conductors are connected. Record all of the voltage calculations on your schematic.

2. Build the circuit that you have drawn in part 1. If the LED does not light, use your DVOM to check the voltage across it. If the voltage across the LED is the supply voltage (6 volts), then it is either open or in backwards. Try turning it around.

3. Use your DVOM to measure the voltage drop across the 220 Ω resistor, and use this voltage and the resistance value to calculate the actual current drawn by the LED. Record this value, then measure all voltages at the nodes, and record these values.

4. On the schematic that you have drawn, assume that there is a short to ground from a point between the 220 Ω resistor and the LED to ground. Draw this short in on your schematic, and calculate the voltages that you will expect at all nodes. Record all of this on your schematic.

5. Take one of your jumpers, and put the short into your circuit as you have drawn it on your schematic. Measure all of the voltages on the nodes, and compare them with your calculated values.

6. Cross out the short on your schematic, and show an open between the two resistors. Calculate the voltages at all nodes, and record them.
7. Remove the short from your circuit, and open the circuit where you have made the open in your schematic. Measure all voltages at the nodes, and compare them with your calculated values.

This laboratory should have helped you to understand how voltage measurements will change with a short or open in a series circuit. A short or open is common in some older vehicles, usually in the circuits feeding the lights where long runs of wire are involved.

E-2

Instrument Panel

Essential Elements: (gg)(1-4)

Unit Objectives:

After completing this instructional unit, you will be able to explain the operations of:

- *lights and switches system and related systems on a typical car*
- *automotive instrument panel*
- *active and passive restraint systems*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain the procedures for troubleshooting an LCD instrument panel*
- *explain the difference between LCD, LED, and VFD instrument panels*

Instrument Panel Input Data

The old style of instrument panel was mostly mechanical with a speedometer cable that drove a mechanical meter, registering the number of miles per hour and the miles driven on the instrument panel. The oil pressure was a pressure gauge on the panel with a tube to the engine. Only the fuel gauge, ammeter, and in some cases the engine temperature had electronic signals to drive either a trouble light indicator or a meter. Today, most manufacturers are putting solid-state electronic instrument panels in their cars because they are more reliable, more accurate, and cheaper to build, with less maintenance over the life of the vehicle.

The various sensors that supply the information on vehicle speed, miles driven, and engine condition all send their data to the instrument panel electronically. Some of the sensors supply an analog signal, and some are able to supply a digital signal. Remember that an analog signal varies continuously with time, and a digital signal is a series of pulses (fig. 1).

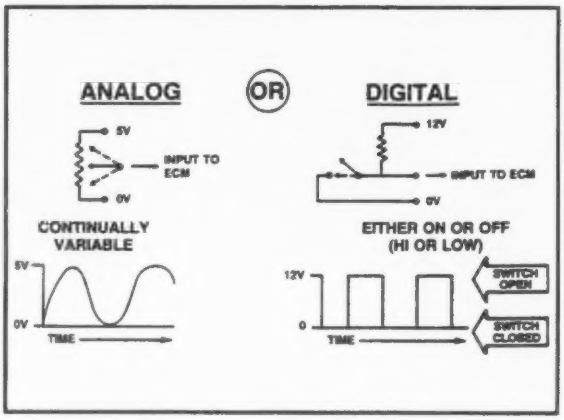


Fig. 1. Analog and digital signals. (Courtesy of General Motors Corporation)

Since the computer or CPU can only work with digital signals, the analog signals have to be changed. The circuitry that changes analog signals to digital is called an *A/D converter* (analog to digital converter) (fig. 2).

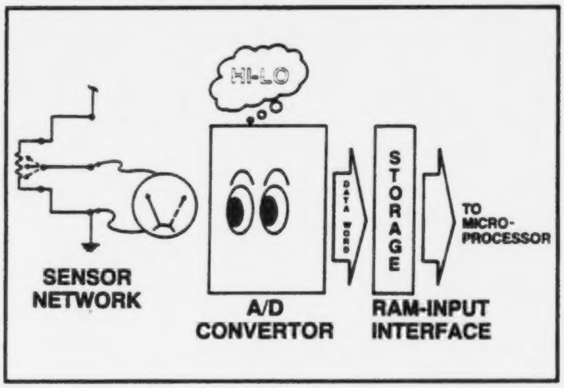


Fig. 2. Processing analog signals. (Courtesy of General Motors Corporation)

Figure 2 shows a fuel sending unit which is a variable resistance connected to a float. Within the upper and lower limits, the voltage from this resistance will vary continuously. The A/D converter changes the voltages to digital binary numbers that represent the voltage received from the sender. These binary numbers can then be used by the computer to cause the display to read out the amount of fuel in the tank and operate any other functions such as low fuel warning signals.

The speedometer and odometer are the primary instruments in the instrument panel. The change to a full digital readout has been gradual, with the stepper motor odometer as a step between the mechanical odometer and a digital readout. The *stepper motor odometer* uses an electric motor to drive the mechanical display (fig. 3).

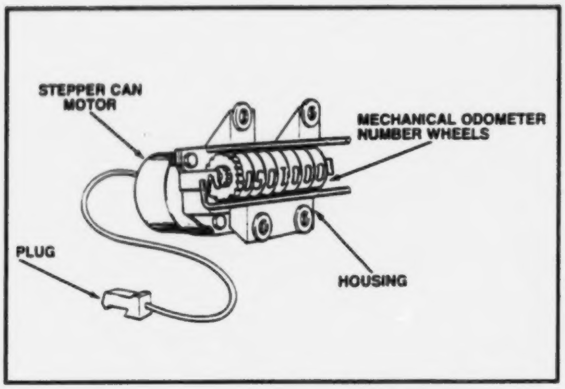


Fig. 3. Stepper motor odometer. (Courtesy of General Motors Corporation)

The electric motor in the stepper motor odometer uses the pulsed signal to move the indicator for each portion of a mile. The stepped pulses that are sent to the odometer are very precise. There are 2,002 pulses sent to the odometer for each mile traveled. This precise pulsed signal comes from the speedometer board.

Testing a stepper motor odometer requires a special tester that will feed a pulsed signal into the unit. If the unit appears to be operating with the test signal, it is probably good. The next place to look for a problem is in the plug or other connections to the stepper motor. With this type of odometer, the wheels and stepper motor should be retained if the unit is replaced to maintain the vehicle mileage. The old wheels and stepper motor should be put into the new unit.

When an electronic digital display, such as the liquid crystal display, is used, then a nonvolatile RAM chip is used to store the mileage information (fig. 4). This type of display will have no mechanical or moving parts.

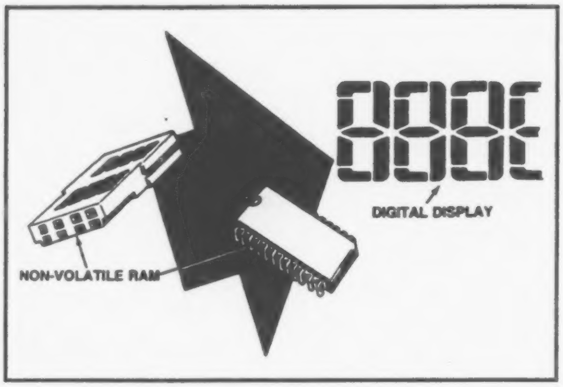

DIGITAL DISPLAY
NON-VOLATILE RAM

Fig. 4. Nonvolatile memory odometer. (Courtesy of General Motors Corporation)

The nonvolatile RAM chip receives data from the microprocessor in the speedometer circuits. This type of chip is used to retain the mileage information when the circuit board is replaced. Putting this chip into the new board will retain the old mileage.

Some people prefer a speedometer with a dial, which is the reason for the *quartz-electric cluster* speedometer (fig. 5). This readout uses the digital signal to control a pointer. The buffered speed signal means the signal has gone through a circuit which conditions it and removes unwanted voltages, resulting in a clean signal that won't confuse the microprocessor or CPU. All computer circuits have reference signals which in figure 5 are generated by the quartz crystal. These reference signals keep everything in order.

Digital Electronic Cluster

The digital electronic cluster shown in figure 6 is basically the same as that in figure 5 except that the readout will be either a number or a bar graph that moves with changes from the sensors. Both types of readout use the same inputs from the sensors. Notice that the readout can be easily changed to read either in English or in metric units.

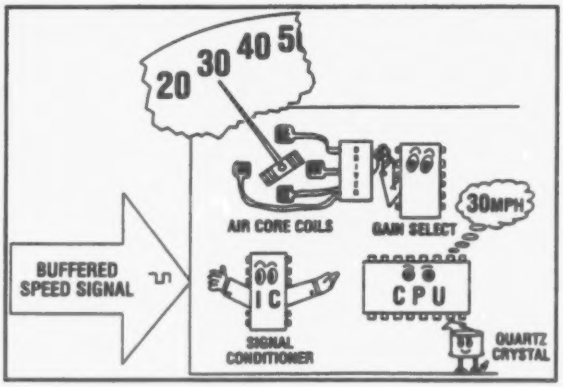

20
30
40
5
AIR CORE COILS
GAIN SELECT
30MPH
BUFFERED SPEED SIGNAL
IC
CPU
SIGNAL CONDITIONER
QUARTZ CRYSTAL

Fig. 5. Quartz-electric cluster. (Courtesy of General Motors Corporation)

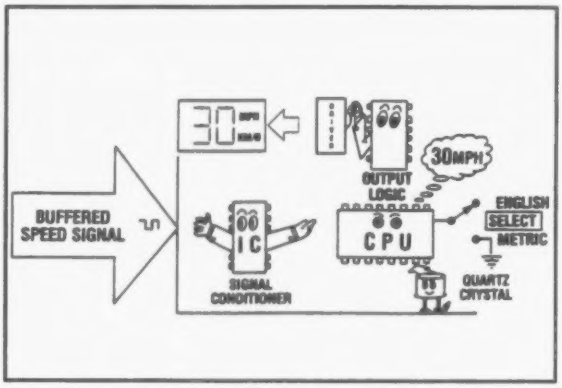

30
30MPH
OUTPUT LOGIC
ENGLISH
SELECT
METRIC
BUFFERED SPEED SIGNAL
IC
CPU
SIGNAL CONDITIONER
QUARTZ CRYSTAL

Fig. 6. Digital cluster circuit. (Courtesy of General Motors Corporation)

The overall operations inside the cluster can be simplified, as shown in figure 7. There is the data in, which is the sensor data received into the microprocessor. The microprocessor analyzes the data and makes decisions based on a variety of inputs and the programs stored in memory. The memory (fig. 7) can be either ROM, RAM, or PROM. The ROM is *read only memory*, which means the microprocessor cannot store anything in this memory, only read from it. The RAM stands for *random access memory*;

however, it is generally understood to mean *read write memory*, and the PROM stands for *programmable read only memory*. The PROM can be changed, usually outside of the cluster. The PROM will hold data that is unique for the vehicle. This data can be changed by pulling the chip and putting it into a programming fixture which is then connected to a computer.

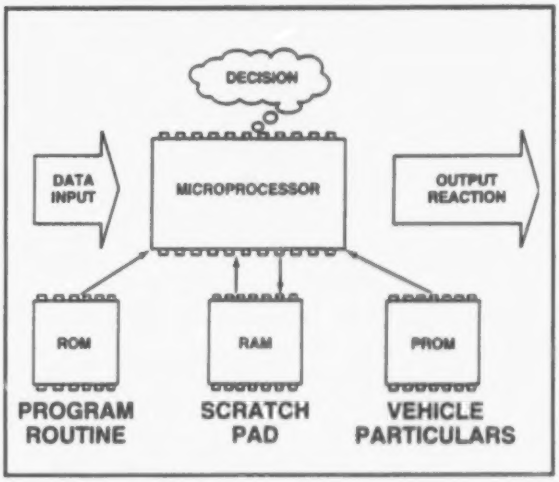

DECISION
DATA INPUT
MICROPROCESSOR
OUTPUT REACTION
ROM
RAM
PROM
PROGRAM ROUTINE
SCRATCH PAD
VEHICLE PARTICULARS

Fig. 7. Decision-making process. (Courtesy of General Motors Corporation)

The CPU or microprocessor can only handle one task at a time. To handle all of the inputs and readouts for a complete instrument panel, it must process each one in turn. Figure 8 shows the CPU reading, processing, and sending data on the fuel level. When it is finished with the fuel level, it will move to the next input in line.

The MUX, which is a multiplexer, will automatically move from one input to the next, allowing the CPU to look at each one in turn. The DEMUX then takes the data from the CPU and sends it to the correct display, also in turn. This allows the CPU to take a sample of each input and show that data on the display.

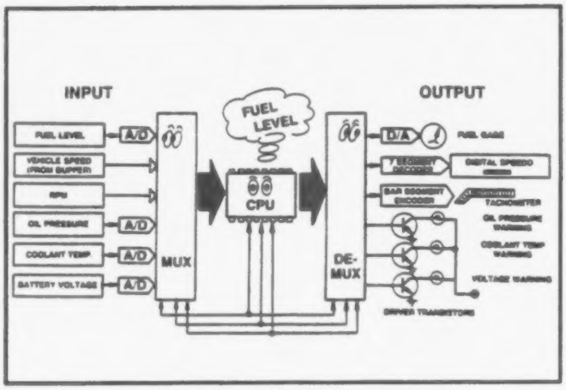

INPUT
OUTPUT
FUEL LEVEL
VEHICLE SPEED (FROM BUFFER)
RPM
OIL PRESSURE
COOLANT TEMP
BATTERY VOLTAGE
A/D
A/D
A/D
A/D
MUX
FUEL LEVEL
CPU
DE-MUX
D/A
FUEL GAGE
7 SEGMENT DECODER
DIGITAL SPEEDO
BAR SEGMENT DECODER
TACHOMETER
OIL PRESSURE WARNING
COOLANT TEMP WARNING
VOLTAGE WARNING
DRIVER TRANSISTORS

Fig. 8. Typical electronic multiplexing. (Courtesy of General Motors Corporation)

For the automotive instrument panel, the CPU will send data often enough for the display to appear to be continuous. Although the MUX will connect the CPU to each input in turn (fig. 9), for some inputs the CPU will average the input data and send a buffered output instead of the raw data to the display.

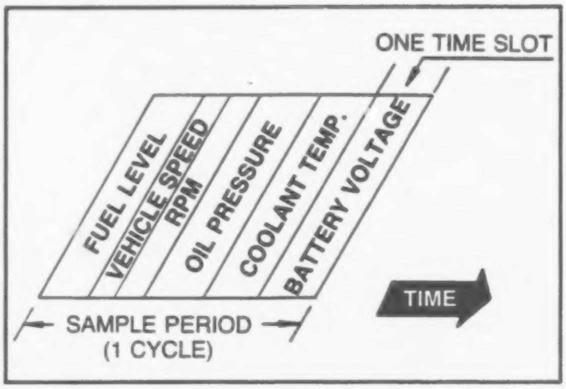

ONE TIME SLOT
FUEL LEVEL
VEHICLE SPEED
RPM
OIL PRESSURE
COOLANT TEMP.
BATTERY VOLTAGE
TIME
SAMPLE PERIOD
(1 CYCLE)

Fig. 9. The sampling period. (Courtesy of General Motors Corporation)

For example, the fuel tank will vary in its readings as the fuel sloshes around. The CPU will average the readings it gets and send this average to the display every 45 seconds. The input data it receives from the fuel tank will be sampled many times every second. When troubleshooting the system, it is important to remember that the output display may not respond as rapidly as the input put there by the technician.

Fuel Measurement

The fuel sensor in the fuel tank is a variable resistor connected to ground (fig. 10). The resistance of the variable resistor changes with the level in the tank.

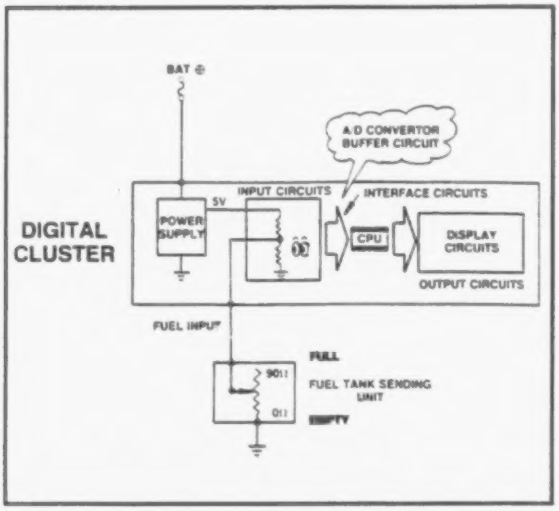


Fig. 10. Digital fuel measurement. (Courtesy of General Motors Corporation)

We can give the resistance values some numbers and analyze the operation of the fuel measurement system. The sending unit shows that it is a 90 Ω variable resistor. Assume that the resistor that is connected directly to the power supply has a value of 50 Ω and the resistor that is in series with it to ground has a value of 100 Ω.

When the fuel tank is full, the resistance in the sender unit will be in parallel with the 100 Ω resistance. This gives an equivalent resistance of 50 Ω, which is the same as the resistance above it. You can calculate the voltage where the two resistors meet as 2.5 volts. The 5 volts from the power supply will be split by the two 50 Ω resistances.

When the tank is empty, the sender unit will have 0 Ω in parallel with the 100 Ω resistor, which will give this same point a voltage of 0 volts. This means the voltage will vary from 0 to 2.5 volts, depending on the level in the fuel tank.

This voltage, which represents the signal from the fuel tank, is sent to an A/D converter. The A/D converter will change the analog voltage to a binary number. The A/D converter can take the voltage range of 0 to 2.5 volts and break it down into 10 pieces or 0.25-volt segments. When the voltage is 0 volts, the binary number that would come from the A/D converter would be 0000_2. When the voltage is 2 volts, that would be 8 of the 0.25-volt segments, so the binary number would be 1000_2, which is 8 in binary.

The CPU will then take the binary number and average it with many other numbers from the A/D converter. It will do this over the specific period of time and then send the average to the display.

Basic Display Devices

You are already familiar with the LED shown in figure 11. The LED can be manufactured to emit different colors by changing the material that it is made with. Red, yellow, and green are the more common colors for LEDs. Yellow seems to work well in the automotive environment since it is easier to see in direct sunlight, which washes out the other colors.

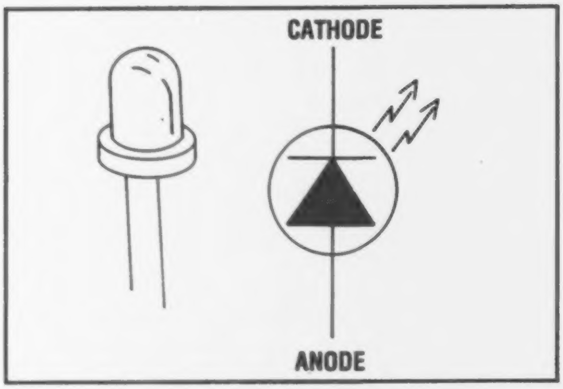

CATHODE
ANODE

Fig. 11. Light-emitting diode. (Courtesy of General Motors Corporation)

The LED can be used as a single point of light for a warning or information light, or it can display numbers. When the LEDs are used to display numbers, they are arranged as a seven-segment LED (fig. 12). Remember that the seven-segment LED can be either common cathode or common anode. When a display is changed, if an "off-the-shelf" package is used, it could be the other type and not work.

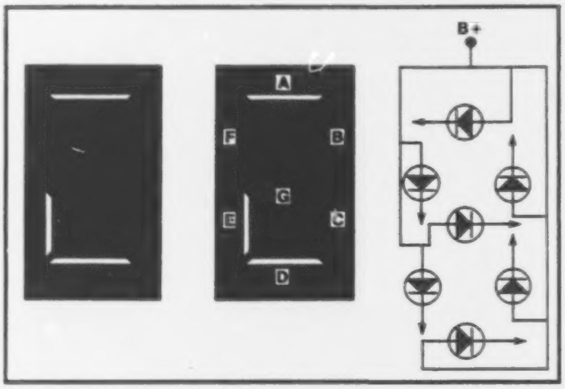


Fig. 12. Seven-segment LED. (Courtesy of General Motors Corporation)

The liquid crystal display (LCD) has become the most popular display for automotive applications and many other applications. Most digital watches use the LCD. One big advantage is that it can be made to display digits, dots, or basically any shape that can be imagined.

The LCD is constructed using two pieces of glass with a special fluid between them. The back piece of glass has a conductive surface. Both pieces of glass are polarized, and a bright halogen bulb is placed behind the display to illuminate it (fig. 13). When an out-of-phase square wave is applied between the conductive surface of the segment and the back piece of glass, the difference in potential across the fluid causes it to twist the light. This twisting of the light will then orient the light so it will pass on through the display.

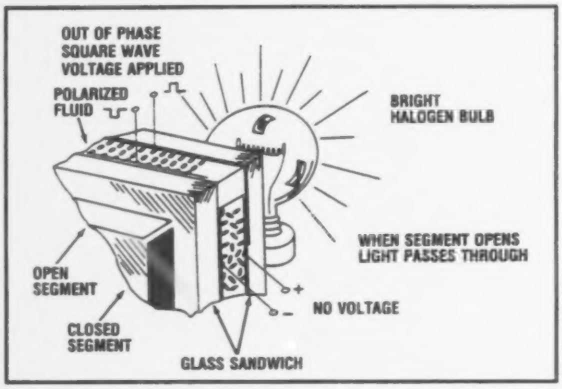

OUT OF PHASE SQUARE WAVE VOLTAGE APPLIED
POLARIZED FLUID
BRIGHT HALOGEN BULB
WHEN SEGMENT OPENS LIGHT PASSES THROUGH
OPEN SEGMENT
+
–
NO VOLTAGE
CLOSED SEGMENT
GLASS SANDWICH

Fig. 13. Liquid crystal display. (Courtesy of General Motors Corporation)

Colored filters are often placed in front of the display to enhance a portion of the display. For example, on the speedometer, the speed above the legal limit can be in red.

Since a strong light is required for the LCD, halogen bulbs are used. A halogen bulb is filled under pressure with an inert gas and, unlike an ordinary bulb, will explode *out* instead of in. An ordinary bulb has a vacuum inside, so when it is broken, the pieces of glass fly inward. The halogen bulb is under pressure, and, when broken, the glass will fly out. *This makes the halogen bulb much more dangerous than an ordinary bulb.*

When replacing a halogen bulb, do not touch the bulb with your fingers. Any oil left on a bulb will cause it to break when it heats up. There are special tools available for replacing halogen bulbs.

Most manufacturers have a system to adjust the brightness of the halogen bulbs behind the display. When the headlights are off, the brightness can be controlled by a photocell which registers the amount of light in the vehicle. When the headlights are on, for most manufacturers, it is assumed that it is evening, and the brightness will be controlled by the variable resistance, which can be set by the driver.

The brightness of the bulb is changed by changing the length of the pulses that are sent to it. The bulb is energized by a series of current pulses, and the duration of the pulse will determine the average amount of current and the brightness of the bulb.

Care must be exercised when cleaning an LCD. The glass will break if too much pressure is applied during the cleaning operation. Pressure on the display can also release some of the fluid, which is caustic. If you get some on your hands, you should immediately wash them. Avoid getting it in your eyes.

Another display that has the advantage of being very bright is the vacuum tube fluorescent display (VFD), shown in figure 14. This display has a phosphorus-coated display surface on a glass tube with a good vacuum in it. Electrons are sent from the control wires inside the display toward the phosphorus, causing it to light in a manner similar to a TV set. Since the display is bright, filters are normally used on the face of the display to reduce the amount of light. This display can also have its brightness controlled electronically.

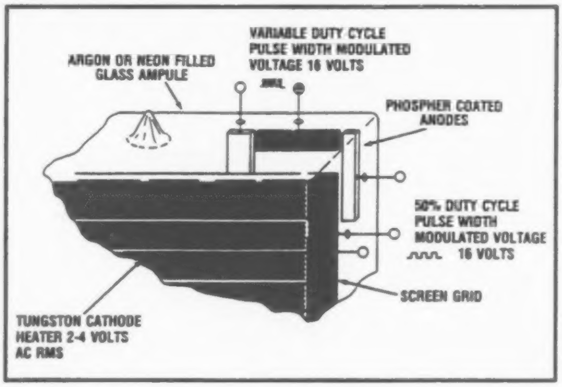


Fig. 14. Vacuum tube fluorescent display. (Courtesy of General Motors Corporation)

Figure 15 shows the instrument panel for a Corvette. This instrument panel is a microprocessor-controlled LCD. The speedometer is on the left side of the display, and the tachometer is on the right. This display has a mechanical odometer driven by a stepper motor, located above the tachometer. In the center are the usual oil pressure, fuel level, and engine temperature, along with some fuel economy information.

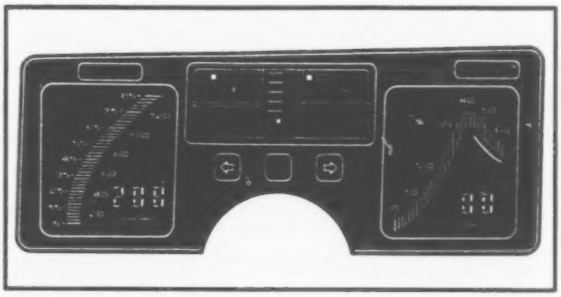


Fig. 15. Corvette liquid crystal display cluster. (Courtesy of General Motors Corporation)

The instrument panel uses the Motorola 6801 microprocessor to process the information that is displayed on the LCD readout. There are nine analog inputs (fig. 16) on the left side of the block diagram. These analog inputs feed into the A/D converter (ADC0809), and then the data goes on the data bus to the microprocessor. A *data bus* is a group of con-ductors on the circuit board that carry information between sections. Since the binary number that comes out of the A/D is an eight-bit number, there will be eight conductors in the data bus carrying the data to the microprocessor.

To the right of the microprocessor is the R6522 interface chip, which has the switch inputs and the speed signal from the sensor and the tachometer signal from the coil. These switch inputs are polled, by the microprocessor, four times a second.

The bottom right of the block diagram shows the LCD drivers and display. The clock input and strobe input are used to control the display. Just above the display is the standby memory. Notice that this memory has arrows showing that data will go both into and out of the memory chip.

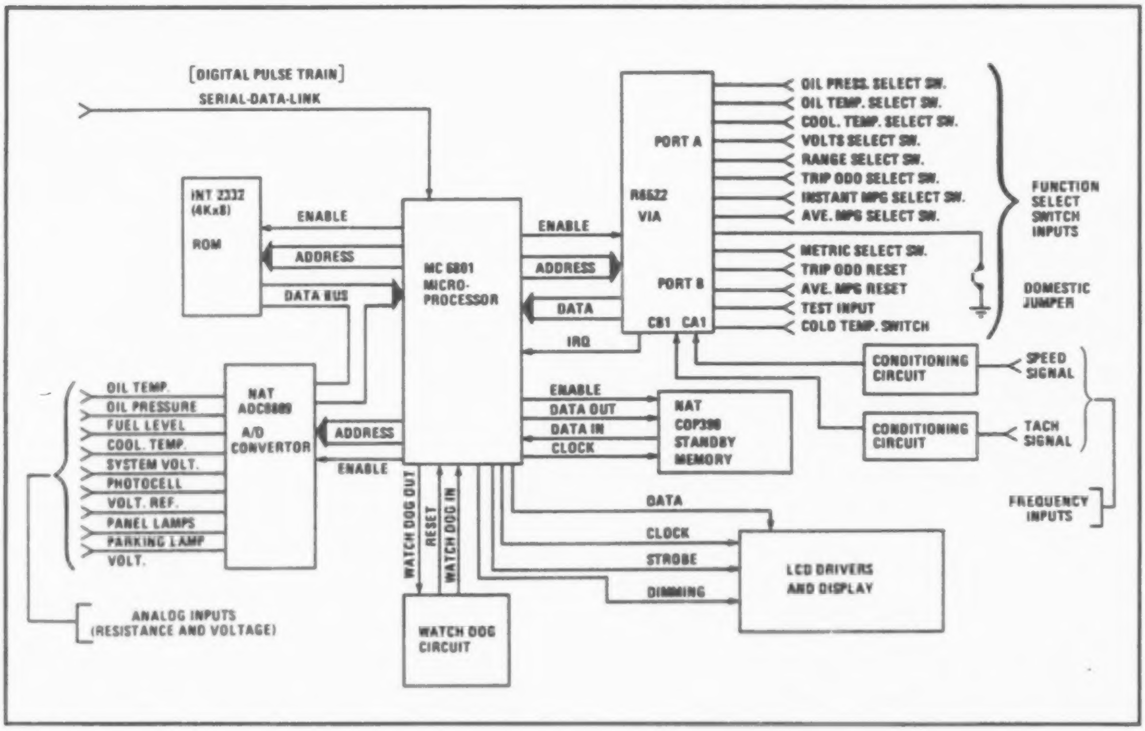

[DIGITAL PULSE TRAIN]
SERIAL-DATA-LINK
INT 2332 (4Kx8) ROM
ENABLE
ADDRESS
DATA BUS
MC 6801 MICRO-PROCESSOR
ENABLE
ADDRESS
DATA
IRQ
PORT A
R6522 VIA
PORT B
CB1
CA1
OIL PRESS. SELECT SW.
OIL TEMP. SELECT SW.
COOL. TEMP. SELECT SW.
VOLTS SELECT SW.
RANGE SELECT SW.
TRIP ODO SELECT SW.
INSTANT MPG SELECT SW.
AVE. MPG SELECT SW.
METRIC SELECT SW.
TRIP ODO RESET
AVE. MPG RESET
TEST INPUT
COLD TEMP. SWITCH
FUNCTION SELECT SWITCH INPUTS
DOMESTIC JUMPER
CONDITIONING CIRCUIT
SPEED SIGNAL
CONDITIONING CIRCUIT
TACH SIGNAL
FREQUENCY INPUTS
OIL TEMP.
OIL PRESSURE
FUEL LEVEL
COOL. TEMP.
SYSTEM VOLT.
PHOTOCELL
VOLT. REF.
PANEL LAMPS
PARKING LAMP
VOLT.
NAT ADC0809 A/D CONVERTOR
ADDRESS
ENABLE
ANALOG INPUTS (RESISTANCE AND VOLTAGE)
ENABLE
DATA OUT
DATA IN
CLOCK
NAT COP398 STANDBY MEMORY
WATCH DOG OUT
RESET
WATCH DOG IN
WATCH DOG CIRCUIT
DATA
CLOCK
STROBE
DIMMING
LCD DRIVERS AND DISPLAY

Fig. 16. Instrument cluster block diagram. (Courtesy of General Motors Corporation)

Exercise

1. What is the circuit called that changes analog signals to digital signals?
2. How many pulses are sent to the stepper motor in an odometer for each mile traveled?
3. Which type of memory chip can be changed in a special fixture?

4. What are the initials for the three common types of electronic instrument panels?

5. What happens differently when a halogen bulb breaks than when an ordinary bulb breaks?

6. How many conductors are in the data bus going to the microprocessor?

7. Which memory type can the microprocessor use to store information in and read it back out?

E-2 Instrument Panel

Workbook

Essential Elements: (gg) (1-4)

Objective

To practice troubleshooting skills on the Corvette instrument panel.

Procedure

The schematic in figure 1 shows the instrument panel connections. Four fuses are shown across the top of the drawing. Each of the inputs to the cluster is numbered, and the wires are all identified. The inputs are all grouped in either the C plug or the D plug. The A and B plugs come from the function select switches.

Examine figure 1, and answer the following questions.

1. What is the color of the wire that goes from the fuel sensor in the fuel tank to the instrument panel?
2. If the instrument panel suddenly lost its illumination, where would you look for the problem first?
3. A customer just returned from Canada with her Corvette and complained that the instrument panel did not respond properly until the interior of the car was warm. What component would probably be the problem?
4. In figure 1, which wire would you check if the left turn signal stopped working?

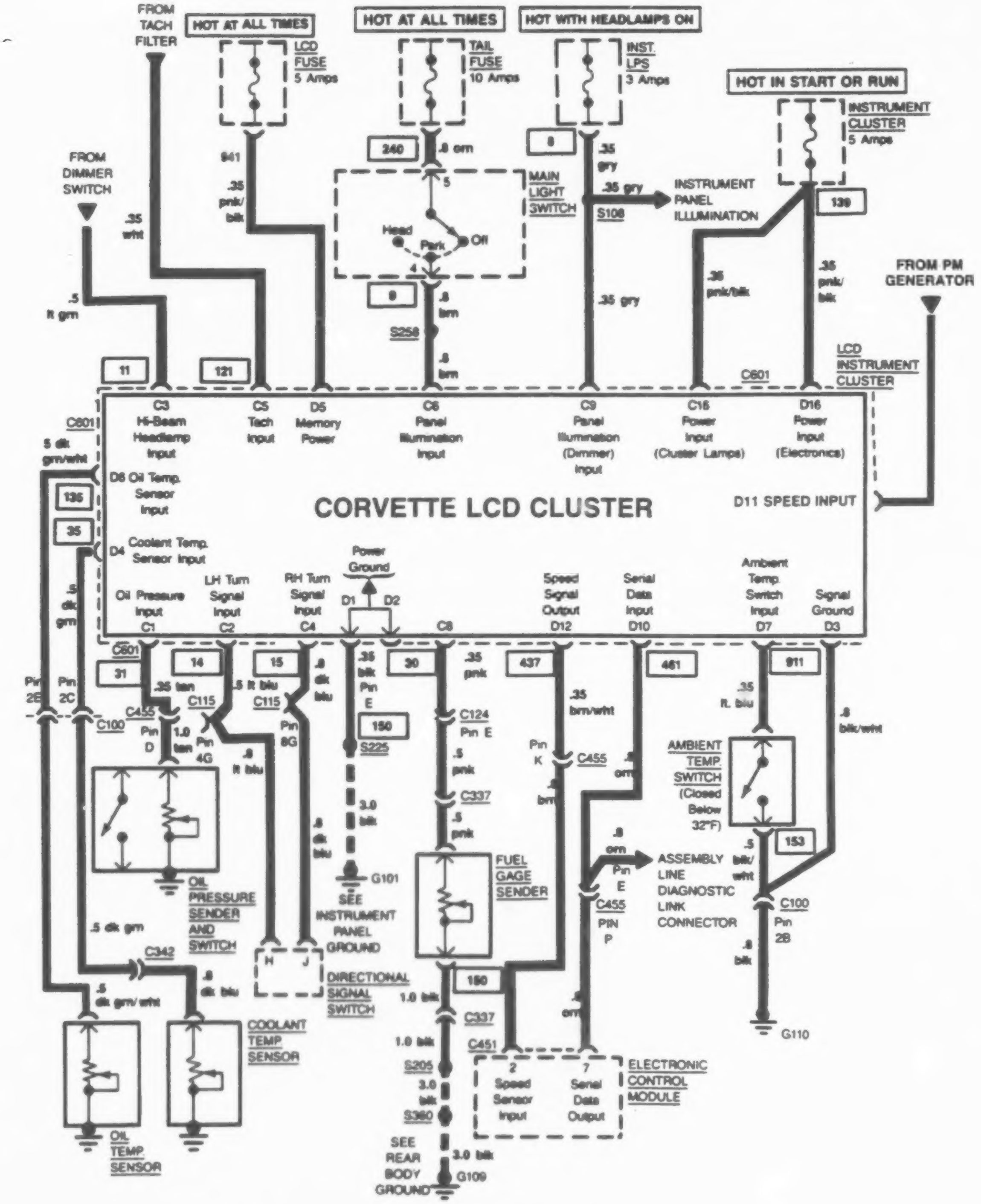

FROM TACH FILTER
HOT AT ALL TIMES
LCD FUSE 5 Amps
HOT AT ALL TIMES
TAIL FUSE 10 Amps
HOT WITH HEADLAMPS ON
INST. LPS 3 Amps
HOT IN START OR RUN
INSTRUMENT CLUSTER 5 Amps
FROM DIMMER SWITCH
941
.35 pnk/blk
.35 wht
240
.8 orn
MAIN LIGHT SWITCH
5
Head
Park
Off
4
8
.35 gry
.35 gry
S108
INSTRUMENT PANEL ILLUMINATION
139
.5 lt grn
9
.8 brn
S258
.8 brn
.35 gry
.35 pnk/blk
.35 pnk/blk
FROM PM GENERATOR
11
121
C601
LCD INSTRUMENT CLUSTER
C3 Hi-Beam Headlamp Input
C5 Tach Input
D5 Memory Power
C6 Panel Illumination Input
C9 Panel Illumination (Dimmer) Input
C16 Power Input (Cluster Lamps)
D16 Power Input (Electronics)
C601
5 dk grn/wht
D6 Oil Temp. Sensor Input
135
CORVETTE LCD CLUSTER
D11 SPEED INPUT
35
D4 Coolant Temp. Sensor Input
Power Ground
D1
D2
Oil Pressure Input C1
LH Turn Signal Input C2
RH Turn Signal Input C4
C8
Speed Signal Output D12
Serial Data Input D10
Ambient Temp. Switch Input D7
Signal Ground D3
C601
31
14
15
30
437
461
911
.5 dk grn
.35 tan
.5 lt blu
.8 dk blu
.35 blk Pin E
.35 pnk
.35 brn/wht
.35 lt. blu
.8 blk/wht
Pin 2E
Pin 2C
C455
C115
C115
C124 Pin E
C100
Pin D
1.0 tan
Pin 4G
Pin 8G
150
S225
.8 lt blu
.5 pnk
Pin K
C455
.8 orn
.8 brn
AMBIENT TEMP SWITCH (Closed Below 32°F)
C337
3.0 blk
.5 pnk
.8 dk blu
.8 orn
Pin E
ASSEMBLY LINE DIAGNOSTIC LINK CONNECTOR
.5 blk/wht
153
G101
FUEL GAGE SENDER
C455 PIN P
C100 Pin 2B
OIL PRESSURE SENDER AND SWITCH
SEE INSTRUMENT PANEL GROUND
.5 dk grn
.8 blk
C342
H
J
DIRECTIONAL SIGNAL SWITCH
150
.5 dk grn/wht
.8 dk blu
1.0 blk
C337
.8 orn
COOLANT TEMP SENSOR
1.0 blk
C451
G110
S205
2 Speed Sensor Input
7 Serial Data Output
ELECTRONIC CONTROL MODULE
3.0 blk
S360
SEE REAR BODY GROUND
3.0 blk
G109
OIL TEMP SENSOR

Fig. 1. Corvette LCD Cluster (Courtesy of General Motors Corporation)

BEST COPY AVAILABLE

E-3

Vehicle Restraint Systems

Essential Elements: **(gg)(1, 2, and 4)**

Unit Objectives:

After completing this instructional unit, you will be able to explain the operations of:

- *lights and switches system and related systems on a typical car*
- *automotive instrument panel*
- *active and passive restraint systems*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how to service a passive seat belt system*
- *explain how to service an air bag restraint system*

Restraint Systems

Over the years, the federal government has passed legislation requiring various seat belt and air bag systems. Also, manufacturers have voluntarily included various safety features as standard equipment. Although they are not presently required by law, air bags will probably become a mandatory feature in automobiles at some time. Most new cars either have or can be equipped with air bags on the driver's side, and many have air bags on the passenger side as an option.

The restraint systems can be divided into two broad categories, active and passive. An *active* system requires the driver or passenger to actively engage the system, such as buckling the seat belt. A *passive* system, like the air bag, is automatically deployed in the event of an accident and requires no active participation from the user. The seat belts that automatically wrap around you when you close the door are passive systems.

The most common seat belt arrangement for most automobiles is the three-point anchoring system. This means the belts for each person are connected to the chassis at three points.

The three points provide an anchor for both the lap belt and the shoulder belt. Most of these systems use a retractor somewhat similar to that shown in figure 1.

The retractor is spring-loaded to gently pull the belt snug during normal operations. When the vehicle stops suddenly as a result of hard braking or hitting something, the pendulum swings forward and latches the ratchet mechanism. The plunger mechanism is an added feature that pulls the seat belt into the mechanism when the vehicle doors are opened.

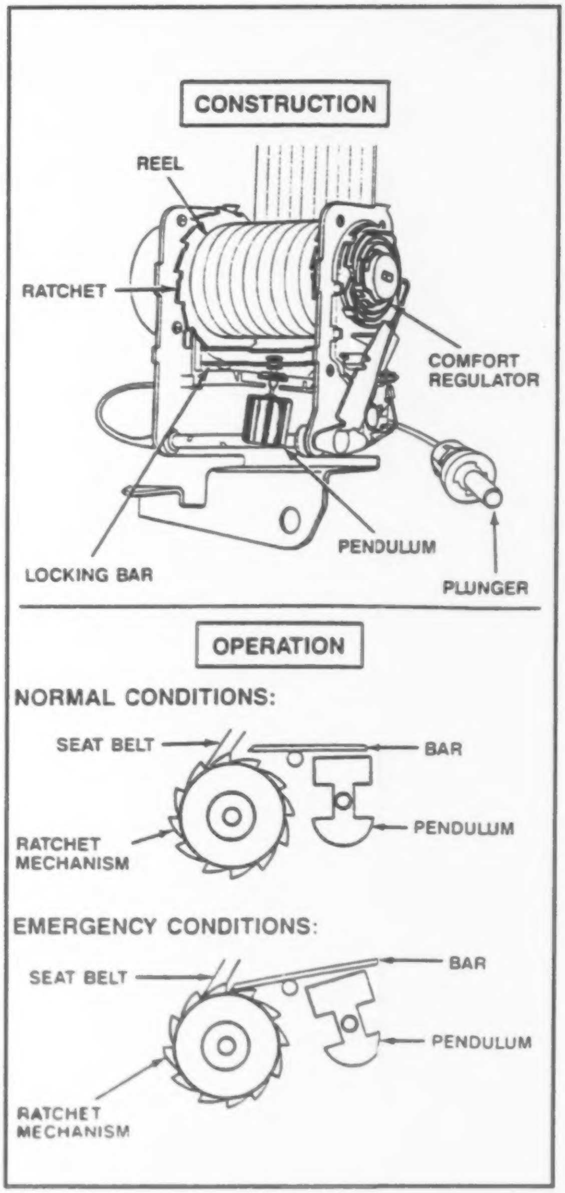

CONSTRUCTION
REEL
RATCHET
COMFORT REGULATOR
PENDULUM
LOCKING BAR
PLUNGER
OPERATION
NORMAL CONDITIONS:
SEAT BELT
BAR
PENDULUM
RATCHET MECHANISM
EMERGENCY CONDITIONS:
SEAT BELT
BAR
PENDULUM
RATCHET MECHANISM

Fig. 1. Safety belt retractor assembly. (Courtesy of Ford Motor Company)

Some manufacturers are simply using a timed warning light and chime when the key is first put in the ignition to alert the driver to use their seat belts.

Figure 2 shows a more sophisticated system that monitors a seat belt switch.

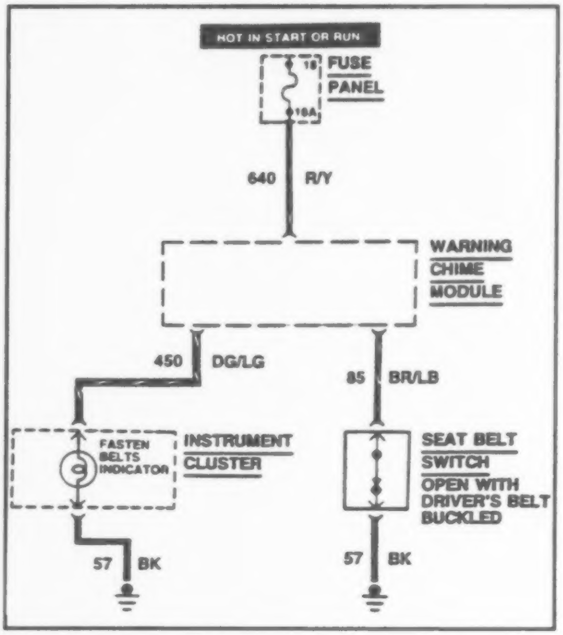

HOT IN START OR RUN
18
FUSE PANEL
10A
640
R/Y
WARNING CHIME MODULE
450
DG/LG
85
BR/LB
FASTEN BELTS INDICATOR
INSTRUMENT CLUSTER
SEAT BELT SWITCH
OPEN WITH DRIVER'S BELT BUCKLED
57
BK
57
BK

Fig. 2. Typical seat belt warning light and chime circuit. (Courtesy of Ford Motor Company)

The seat belt switch is a grounding switch located on the driver's seat belt buckle assembly. If the driver puts the seat belt on before putting the key in the ignition, no light or chime comes on. When the driver puts the key in the ignition before the seat belt buckle assembly is connected, the warning chime and light come on and stay on for four to eight seconds.

Passive Seat Belt

The passive seat belt is a motorized system that wraps the seat belt around the occupant of the car when the car door is closed. Only the shoulder belt is wrapped around the occupant; the lap belt still has to be attached manually.

Figure 3 shows a system used by Ford in its Escort, Tempo/Topaz and Thunderbird/Cougar lines.

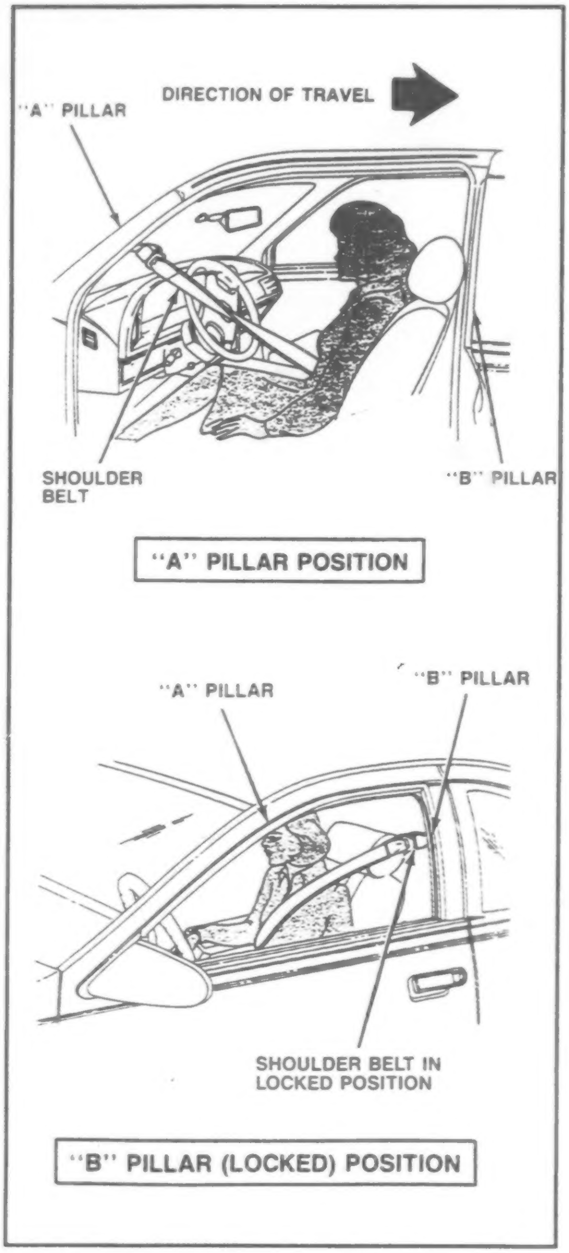

"A" PILLAR
DIRECTION OF TRAVEL
SHOULDER BELT
"B" PILLAR
"A" PILLAR POSITION
"A" PILLAR
"B" PILLAR
SHOULDER BELT IN LOCKED POSITION
"B" PILLAR (LOCKED) POSITION

Fig. 3. Belt movement. (Courtesy of Ford Motor Company)

When the occupant enters the car, closes the car door, and turns on the ignition, a motor located at the base of the pillar, labeled "B" in the drawing, starts to pull a metal tape. This metal tape is connected to the belt, which moves across the occupant as shown in the drawing. The motor will continue running until the belt reaches the limit switch (fig. 4). There are limit switches at both ends of the belt travel. The limit switches tell the electronic module the status of the system.

The electronic module accepts inputs from the limit switches, door ajar switch, emergency release switch, inertia switch, and ignition switch.

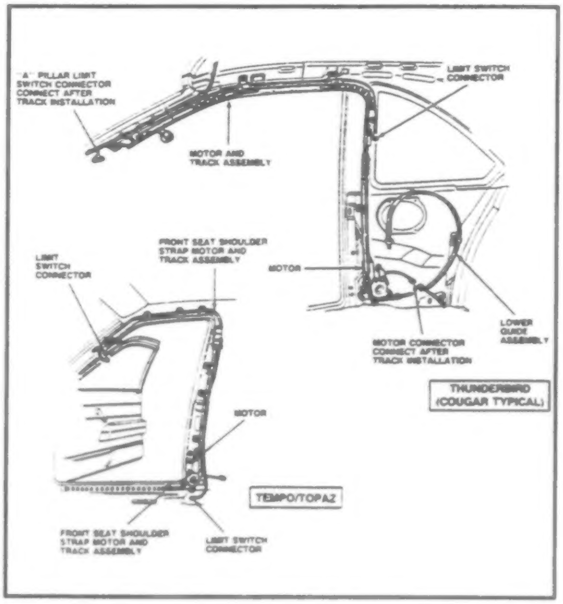

"A" PILLAR LIMIT SWITCH CONNECTOR CONNECT AFTER TRACK INSTALLATION
LIMIT SWITCH CONNECTOR
MOTOR AND TRACK ASSEMBLY
FRONT SEAT SHOULDER STRAP MOTOR AND TRACK ASSEMBLY
LIMIT SWITCH CONNECTOR
MOTOR
LOWER GUIDE ASSEMBLY
MOTOR CONNECTOR CONNECT AFTER TRACK INSTALLATION
THUNDERBIRD (COUGAR TYPICAL)
MOTOR
TEMPO/TOPAZ
FRONT SEAT SHOULDER STRAP MOTOR AND TRACK ASSEMBLY
LIMIT SWITCH CONNECTOR

Fig. 4. Motorized track system. (Courtesy of Ford Motor Company)

When the car is driven with no passenger, the passenger side belt moves to the B position or the rear of the car and remains there until the passenger door is opened.

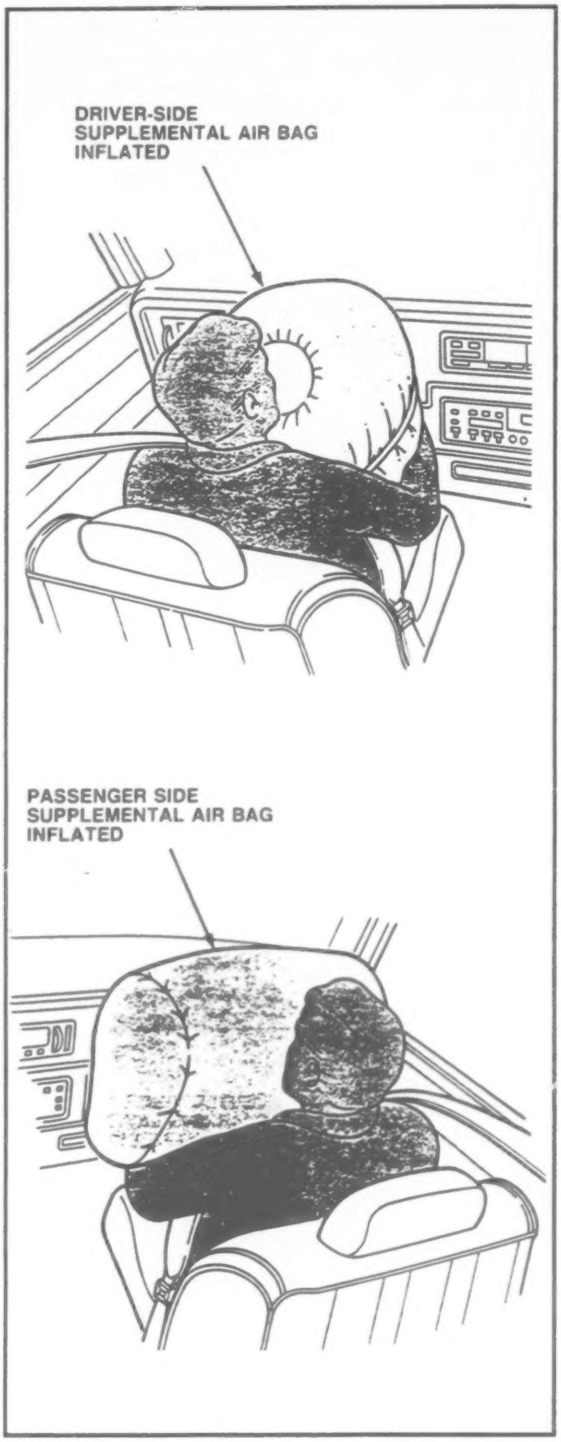

DRIVER-SIDE
SUPPLEMENTAL AIR BAG
INFLATED
PASSENGER SIDE
SUPPLEMENTAL AIR BAG
INFLATED

Fig. 5. Air bag inflated. (Courtesy of Ford Motor Company)

Air Bag Restraint System

The air bag restraint system consists of a large nylon bag that is rapidly inflated and then deflated when the vehicle experiences a stopping force equal to running into a parked car at over 28 miles per hour. The air bag will completely inflate within 65 milliseconds (see fig. 5). After inflating, the bag will then promptly deflate. This system is designed to be used with seat belts. The seat belts are needed to hold the occupants in position for the air bag to work and to protect the occupants in an accident that is not severe enough to activate the air bags.

The air bag system is designed to operate only once and then be replaced. For most cars, the air bag for the driver is located in the center of the steering wheel, and for the passenger it is located in the dash (fig. 6).

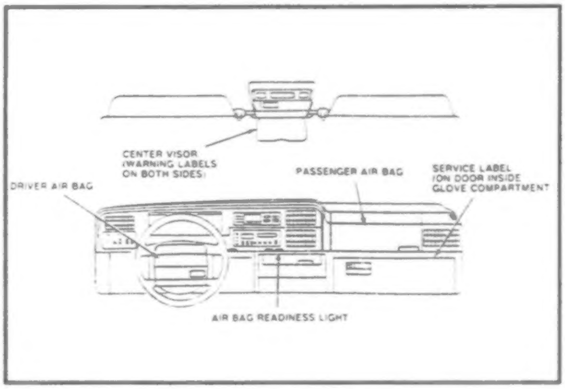

CENTER VISOR
(WARNING LABELS
ON BOTH SIDES)
DRIVER AIR BAG
PASSENGER AIR BAG
SERVICE LABEL
(ON DOOR INSIDE
GLOVE COMPARTMENT
AIR BAG READINESS LIGHT

Fig. 6. Air bag and warning light locations. (Courtesy of Ford Motor Company)

The air bag on the driver's side consists of an inflator, mounting plate and retainer ring, bag assembly, and steering wheel trim cover (fig. 7). The inflator assembly (fig. 8) consists of the igniter assembly, generant housing, filter cooling system, and elastomeric seals.

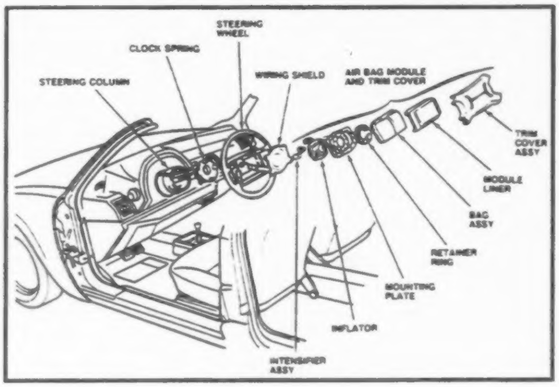

STEERING WHEEL
CLOCK SPRING
STEERING COLUMN
WIRING SHIELD
AIR BAG MODULE AND TRIM COVER
TRIM COVER ASSY
MODULE LINER
BAG ASSY
RETAINER RING
MOUNTING PLATE
INFLATOR
INTENSIFIER ASSY

Fig. 7. Driver air bag module–exploded view. (Courtesy of Ford Motor Company)

When the crash sensors operate as a result of a crash, battery voltage is sent to the inflator assembly. The battery voltage goes to the igniter assembly and is converted to heat, which ignites the sodium azide/copper oxide gas generant inside the inflator. This material burns very rapidly, producing harmless nitrogen gas. The gas is cooled and filtered on its way to inflating the bag.

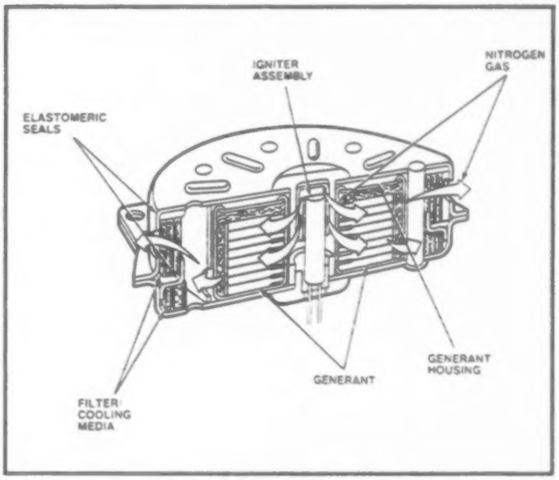

IGNITER ASSEMBLY
NITROGEN GAS
ELASTOMERIC SEALS
GENERANT HOUSING
GENERANT
FILTER/ COOLING MEDIA

Fig. 8. Inflator assembly. (Courtesy of Ford Motor Company)

When the inflator operates, it causes a loud bang, which is often not heard by the occupants as a result of the crash noises. Figure 9 shows a breakdown of the igniter assembly.

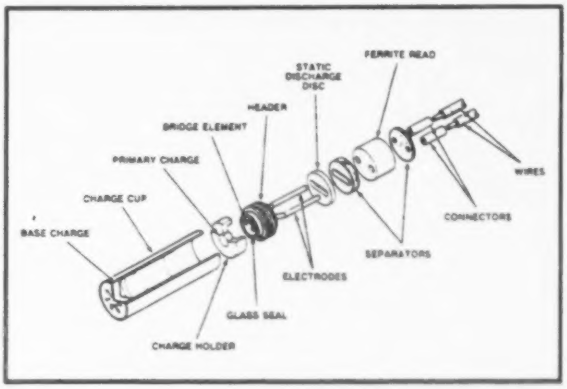

FERRITE READ
STATIC DISCHARGE DISC
HEADER
BRIDGE ELEMENT
PRIMARY CHARGE
CHARGE CUP
BASE CHARGE
WIRES
CONNECTORS
SEPARATORS
ELECTRODES
GLASS SEAL
CHARGE HOLDER

Fig. 9. Igniter assembly. (Courtesy of Ford Motor Company)

The passenger air bag assembly, which is still an option with many manufacturers, is mounted above the glove compartment and to the right of the instrument panel on Ford vehicles. It consists of the inflator, air bag assembly, and the trim (fig. 10). This unit operates in the same manner as the driver side air bag, although in many vehicles it has a larger bag to accommodate the greater area that passengers may be seated in.

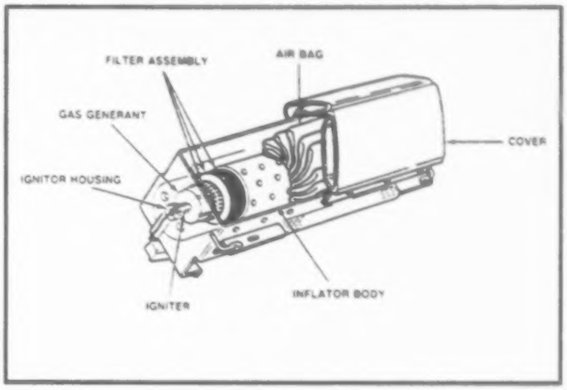

FILTER ASSEMBLY
AIR BAG
GAS GENERANT
COVER
IGNITOR HOUSING
INFLATOR BODY
IGNITER

Fig. 10. Typical passenger air bag assembly. (Courtesy of Ford Motor Company)

The air bag system is controlled by the diagnostic monitor, which contains the microprocessor. The diagnostic monitor receives inputs from the crash sensors and other electrical components. The monitor also does a self-check of its internal circuits and energizes the system readiness indicator during the checkout and if a fault is detected. The system used by Ford has the readiness indicator flash if there is a fault. The number of flashes indicates what the fault is. Under certain fault conditions, the system will disarm. If the indicator lamp fails and a fault is found, it will sound a buzzer to alert the occupants that the system is not functional.

The air bag system is powered directly from the battery and can operate with the ignition off and with no passengers in the vehicle. Figure 11 shows how the system is wired into the car. There are a total of four sensor locations in the front part of the car. A sensor is located on each of the front fender areas and in the front and rear center of the engine compartment.

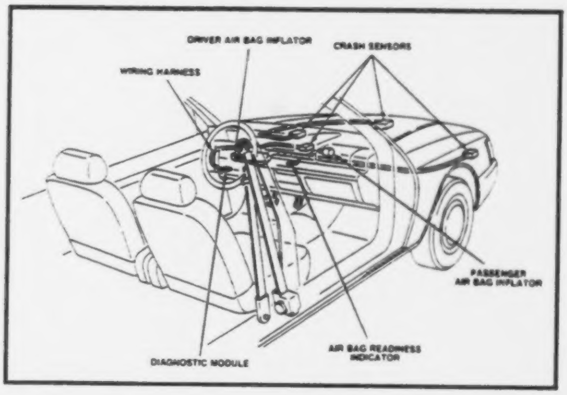

DRIVER AIR BAG INFLATOR
CRASH SENSORS
WIRING HARNESS
PASSENGER AIR BAG INFLATOR
AIR BAG READINESS INDICATOR
DIAGNOSTIC MODULE

Fig. 11. Electrical system. (Courtesy of Ford Motor Company)

The sensor part of the air bag system uses the three crash sensors located on each side of the engine compartment and behind the radiator. The sensor behind the radiator has a second sensor located inside the unit, which is a safing sensor. The other safing sensor is located at the rear of the engine compartment in the cowl area.

The safing sensors are designed to close with less deceleration than the crash sensors. The system will only operate when at least one safing sensor and one crash sensor have operated. The crash sensor needs an impact equal to hitting a brick wall at 14 mph or more to operate. This is the equivalent of hitting a parked car, of equal size and weight, at 28 mph. The air bags should not deploy if the crash does not have this much deceleration.

Figure 12 shows how the sensors are made. A strong bias magnet holds a steel ball that is coated with gold to retard corrosion. When the car hits an object, the steel ball is thrown off the magnet and moves down a tube toward the double set of electrical contacts. When it makes contact with the contacts, the circuit is complete.

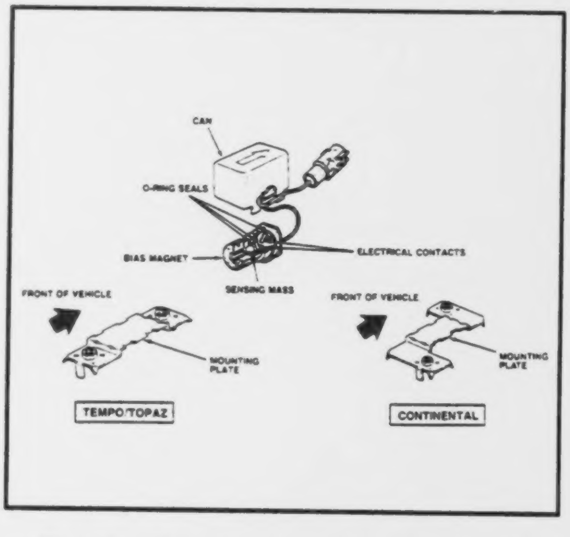

CAN
O-RING SEALS
BIAS MAGNET
ELECTRICAL CONTACTS
SENSING MASS
FRONT OF VEHICLE
MOUNTING PLATE
FRONT OF VEHICLE
MOUNTING PLATE
TEMPO/TOPAZ
CONTINENTAL

Fig. 12. Sensor construction. (Courtesy of Ford Motor Company)

Figure 13 shows how the safing sensors are wired into the air bag diagnostic module. Notice that the simplified circuit at the bottom of the schematic shows the safing sensor in series with the air bags, which are in series with the front crash sensors. The sensors are in parallel so that only one of the safing sensors and only one of the front sensors have to make contact and there will be current through the air bag igniter, causing the air bag to be deployed.

This system operates very fast. It is designed to fully inflate the air bags within 65 milliseconds from the moment of impact.

Number of Flashes	**Probable Cause**
No Lamp	Inoperative air bag lamp circuit.
Continuous Lamp	Diagnostic module disconnected or faulty.
3	Loss of air bag deployment circuit.
5	Shorted crash sensor deployment circuit.
10	Firing circuit disarm device blown.
4	Potential short in air bag deployment circuit or improperly grounded dash panel sensor.
6	Driver air bag circuit inoperative.
7	Passenger air bag circuit inoperative.
8	Forward crash sensor improperly attached or grounded.
9	Open forward crash sensor deployment circuit.
2	All forward crash sensors disconnected.

Table 1. Air bag fault code chart. (Courtesy of Ford Motor Company)

Diagnosing and Servicing the Air Bag System

The diagnostic monitor checks the air bag system and will flash the indicator lamp to show what the problem is. If the lamp is burned out, it will sound an audible alarm. The list of flashes shown in table 1 is for the Ford system only and is included only for illustration. Before servicing an air bag system, you must have the proper service manual and follow the instructions carefully.

Remember that the air bag assembly has an explosive device in it which inflates the bag. Hold the bag assembly with the trim away from you so that, if it inflates, the bag will burst out away from you. Also when placing the unit on a counter, place the trim up so that if it accidentally inflates, the bag will inflate up inside of pushing the whole assembly up. The igniter is very sensitive to electrical currents and if not properly handled, when it is outside of the car, it can be set off from static electricity or a two-way radio or mobile phone that is operated close to it.

The current from your meter can cause the igniter to go off during a resistance check. Follow the instructions in the manufacturer's service manual before taking any resistance readings on the system.

If a vehicle with a live air bag system is to be scrapped, the air bags should be deployed first. Check the manufacturer's manual for the specific instructions. There should be no people in the car when the bags are deployed. The bags can be deployed by jumping the plugs to the sensors to simulate a crash.

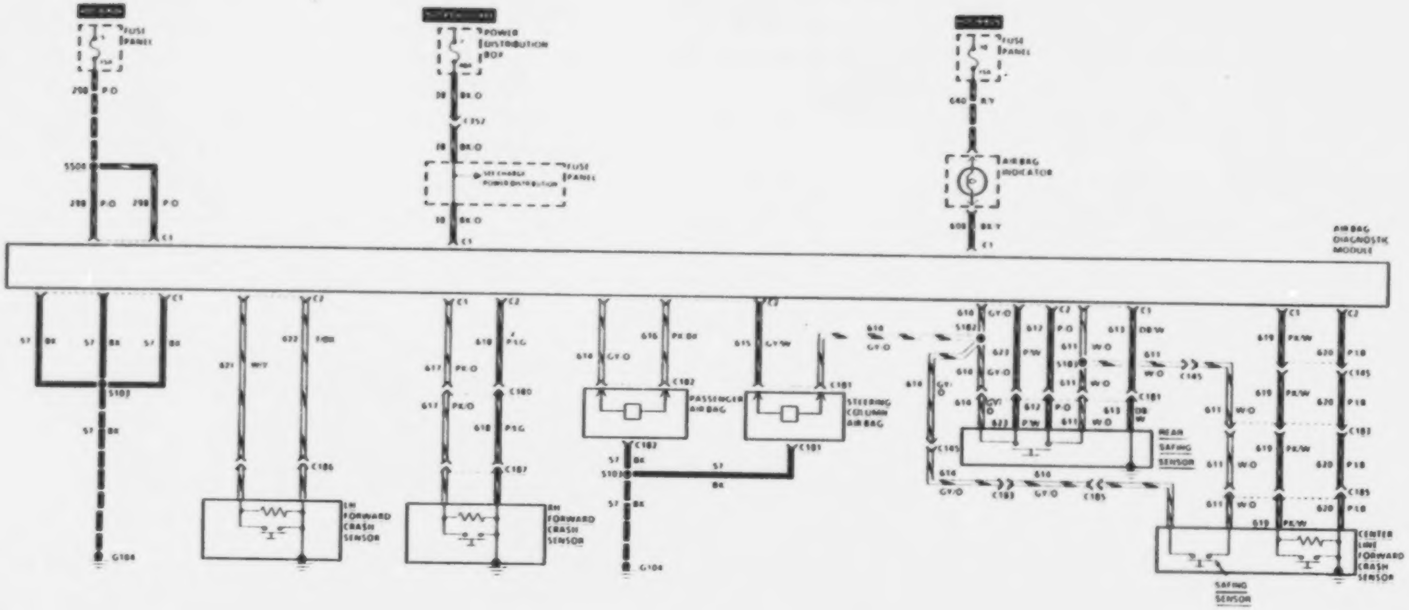
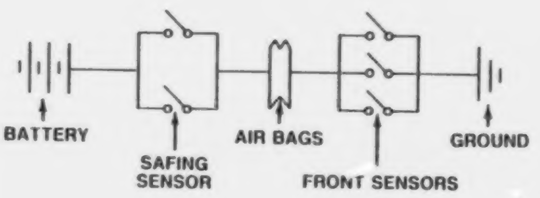

FUSE PANEL
298 P/O
S504
POWER DISTRIBUTION BOX
38 BK/O
C257
SEE CHARGE POWER DISTRIBUTION
FUSE PANEL
C1
C2
57 BK
S103
G104
621 W/Y
622 T/DB
C186
LH FORWARD CRASH SENSOR
617 PK/O
618 P/LG
C180
C187
RH FORWARD CRASH SENSOR
614 GY/O
616 PK/DB
C102
PASSENGER AIR BAG
615 GY/W
C101
STEERING COLUMN AIR BAG
640 R/Y
AIR BAG INDICATOR
608 BK/Y
AIR BAG DIAGNOSTIC MODULE
S102
612 P/O
623 P/W
611 W/O
613 DB/W
C181
C185
C183
619 PK/W
620 P/LB
REAR SAFING SENSOR
SAFING SENSOR
CENTER LINE FORWARD CRASH SENSOR

Fig. 13. Air bag system schematic. (Courtesy of Ford Motor Company)

AIR BAG DEPLOYMENT CIRCUIT


BATTERY
SAFING SENSOR
AIR BAGS
FRONT SENSORS
GROUND

If the air bags do not deploy as a result of shorting the sensors, then the bags should be removed from the car and placed in a clear area with the trim facing up. Check the manufacturer's instructions for the proper procedure, and set off the bags by connecting the air bag assembly to a car battery. You should be at least 20 feet away from the bags when you set them off.

Exercise

1. What is the difference between an active and a passive restraint system?

2. At what speed must you be going when you run into a parked car that is about equal to your car in weight and size for the air bags to deploy?

3. How long does it take for the air bag to completely inflate after impact?

4. How many times can an air bag be used before it should be replaced?

5. How many of the crash sensors and safing sensors have to make contact to deploy the air bag?

6. If you enter a Ford vehicle with an air bag system installed and you find the air bag ready light is flashing, what does this mean?

7. When a vehicle has an air bag system for both the driver and passenger, is there is any need for seat belts?

E-3 Vehicle Restraint Systems

Workbook

Essential Elements: (gg)(1, 2, and 4)

Function Table Warnings	
Action	**Result**
Belt does not properly reach "B" pillar; after approximately 7.5 seconds.	Fasten belt indicator (IP) flashes
Release lever in UP position, Ignition ON.	1. Fasten belt indicator (IP) flashes. 2. Release lever warning indicator flashes. 3. Chime sounds continuously.

Table 1. Passive Restraint System Function Tables (Courtesy of Ford Motor Company)

Procedure

Use figure 1 and table 1 to determine how the seat belt system will respond to the following actions. Write your answer on a separate piece of paper, and then compare your answers with the answers given at the end of the lesson.

1. With the car door closed, the ignition switch is turned on.
2. With the ignition switch in the off position, the door is opened.
3. The door is open, and the ignition switch is turned on.
4. With the door closed, the ignition switch is turned on.
5. With the inertia switch in the open condition and the door open, the ignition switch is turned on.
6. With the inertia switch in the open condition and the door open, the ignition switch is turned off.

Assume that you are troubleshooting this seat belt system, and use figure 1 and table 1 to determine what you should do next.

7. You can hear the transport motor run, but the seat belt does not move although you can move it manually.
8. When the door is closed with the ignition either on or off, the seat belt moves to "B" pillar.

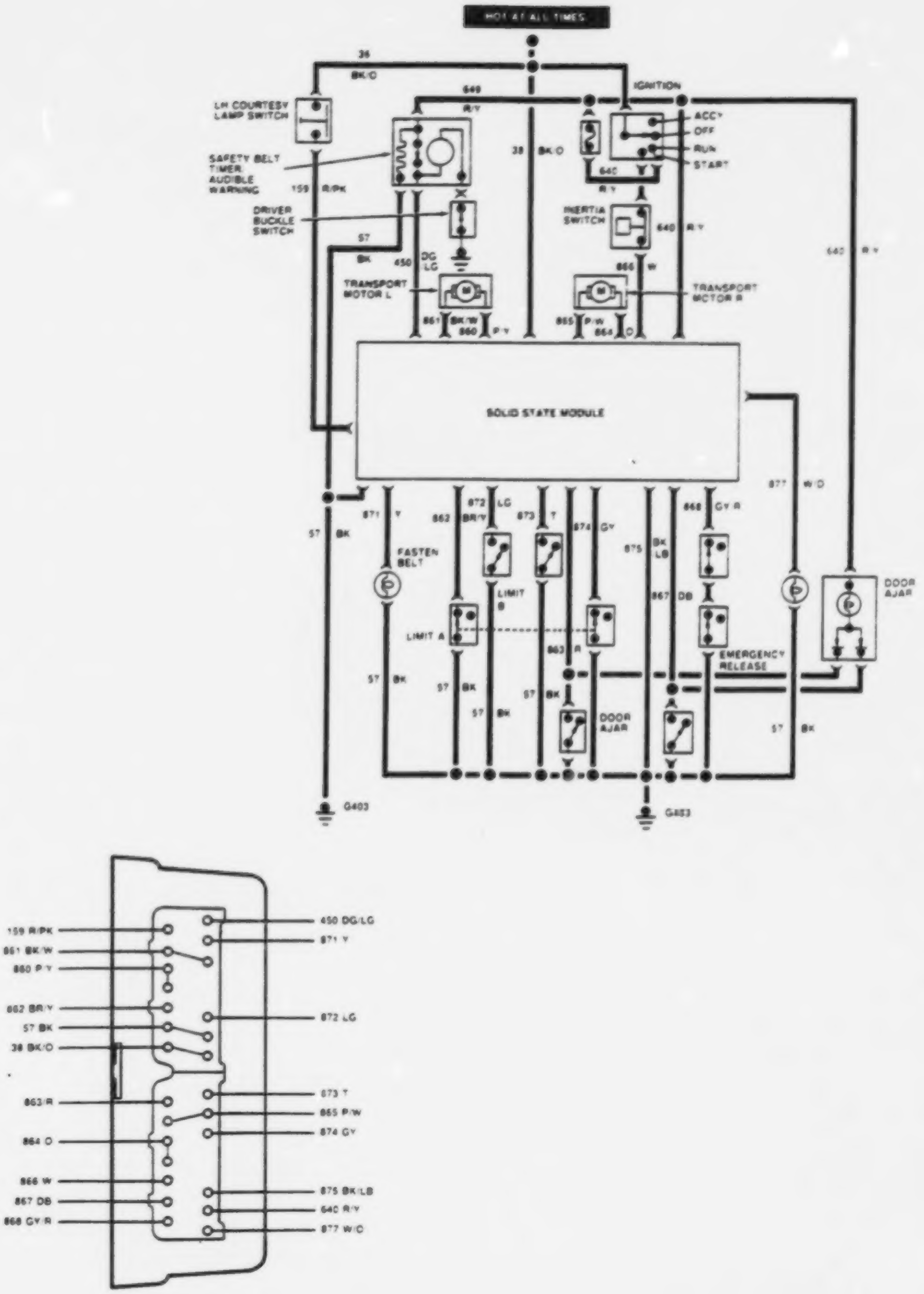

HOT AT ALL TIMES
36
BK/O
LH COURTESY LAMP SWITCH
640
R/Y
IGNITION
ACCY
OFF
RUN
START
SAFETY BELT TIMER AUDIBLE WARNING
159 R/PK
38 BK/O
640
R/Y
DRIVER BUCKLE SWITCH
INERTIA SWITCH
640 R/Y
57
BK
450 DG LG
866 W
640 R/Y
TRANSPORT MOTOR L
TRANSPORT MOTOR R
861 BK/W
860 P/Y
865 P/W
864 O
SOLID STATE MODULE
877 W/O
871 Y
862 BR/Y
872 LG
873 T
874 GY
875 BK LB
868 GY R
57 BK
FASTEN BELT
LIMIT B
LIMIT A
863 R
867 DB
EMERGENCY RELEASE
DOOR AJAR
DOOR AJAR
57 BK
57 BK
57 BK
57 BK
57 BK
G403
G403
159 R/PK
861 BK/W
860 P/Y
862 BR/Y
57 BK
38 BK/O
863/R
864 O
866 W
867 DB
868 GY/R
450 DG/LG
871 Y
872 LG
873 T
865 P/W
874 GY
875 BK/LB
640 R/Y
877 W/O

Fig. 1. Typical passive restraint system schematic. (Courtesy of Ford Motor Company)

Unit
F
Engine Electronic Control Systems

F-1 Automotive Sensors
F-2 Engine Fuel Delivery Systems
F-3 Ignition Systems
F-4 Emission Control Systems

F-1

Automotive Sensors

Essential Elements: (gg)(1, 2, and 4)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamental operation of each of the following:

- *automotive sensors*
- *the fuel delivery system*
- *the electronic ignition system*
- *the emission control system*
- *the diesel fuel delivery and control system*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how the various sensors on the automobile operate*
- *explain how the voltage divider method is used to provide a signal to the computer from a sensor*

Introduction

The input sensors are the eyes of the various automotive computers. The accuracy of the information fed by the sensors to the computer is important. This high accuracy requirement for the sensors has resulted in the use of the most current high technology available.

The final signal that is sent to the computer is always in the form of a signal voltage. If the signal voltage is analog, the internal A/D converter must change it before the microprocessor can use it (see fig. 1).

Potentiometers

All sensors either generate their own voltage or control a reference voltage. The sensors that use a reference voltage will get it from the microprocessor. Figure 2 shows how the microprocessor supplies the reference voltage to a sensor which is a variable resistance. The variable resistance or potentiometer feeds back a portion of the reference voltage, which is converted by the A/D converter to a binary signal that can be accepted by the microprocessor.

The potentiometer in figure 2 is connected to the throttle plate and acts as a position sensor, telling the microprocessor the position of the plate. The microprocessor provides a 5-volt reference signal to the potentiometer. When the throttle is fully open, most of the 5 volts goes to the A/D converter. When the throttle is closed, a very low voltage or 0 volts goes to the A/D converter.

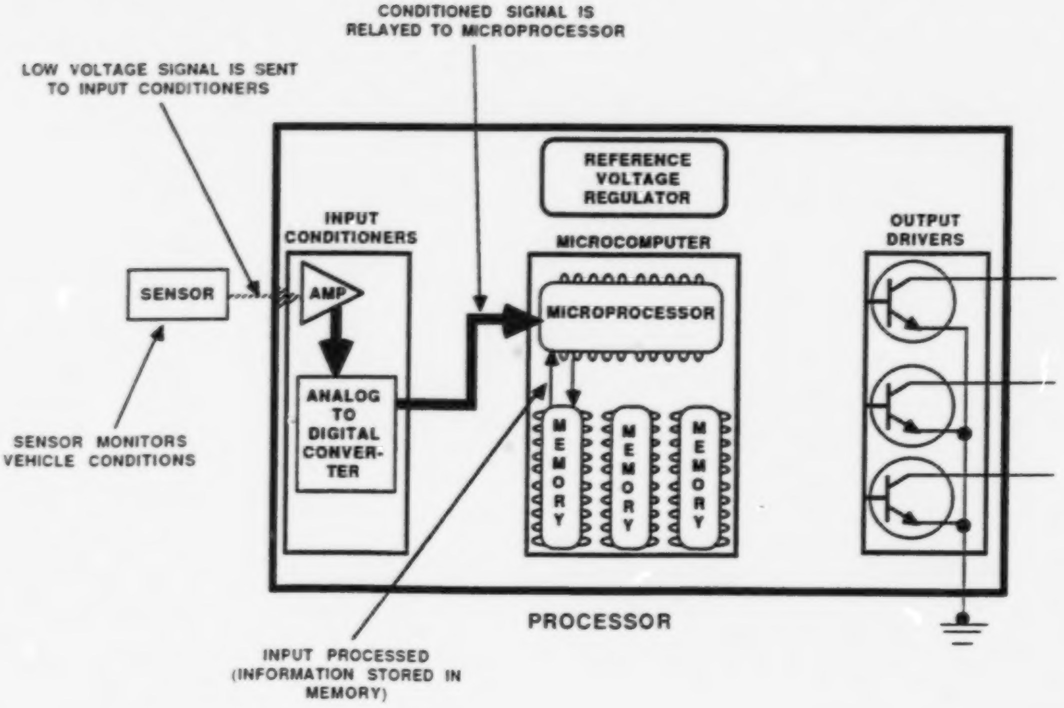

CONDITIONED SIGNAL IS RELAYED TO MICROPROCESSOR
LOW VOLTAGE SIGNAL IS SENT TO INPUT CONDITIONERS
REFERENCE VOLTAGE REGULATOR
INPUT CONDITIONERS
MICROCOMPUTER
OUTPUT DRIVERS
SENSOR
AMP
MICROPROCESSOR
ANALOG TO DIGITAL CONVERTER
MEMORY
MEMORY
MEMORY
SENSOR MONITORS VEHICLE CONDITIONS
PROCESSOR
INPUT PROCESSED (INFORMATION STORED IN MEMORY)

Fig. 1. Input conditioning. (Courtesy of Ford Motor Company)

The potentiometer connected to the throttle is made by placing resistive material in a semicircle on a flat plate in the body of the potentiometer (fig. 3). A wiper is connected to the center terminal and becomes the movable part of the resistor. This wiper will move across the resistive material, resulting in a change in resistance between the wiper terminal and the other two terminals.

The current passing through the resistive material in the potentiometer results in a voltage drop. The voltage drop referenced to ground will change according to the position of the wiper in the potentiometer. Most potentiometers used as position sensors are linear potentiometers. A linear potentiometer will change resistance at the same rate that the control is turned or moved across the resistance. A popular nonlinear potentiometer has a logarithmic taper, which means that the resistance changes at a logarithmic rate for a uniform rate of change in the position of the wiper.

The potentiometer used to sense the position of the EGR valve is constructed so that the wiper moves straight up and down on the resistive material (fig. 4). There are many ways to construct a

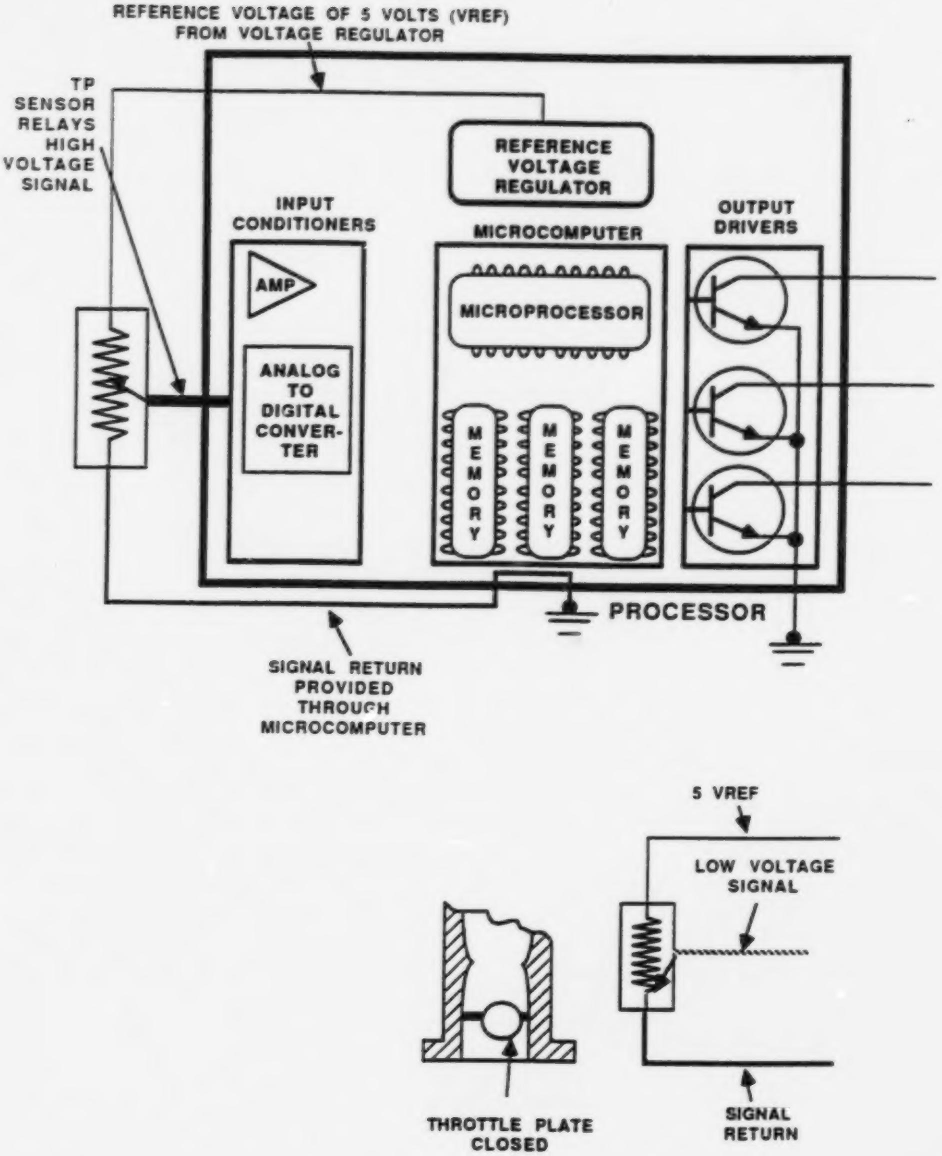

REFERENCE VOLTAGE OF 5 VOLTS (VREF)
FROM VOLTAGE REGULATOR
TP
SENSOR
RELAYS
HIGH
VOLTAGE
SIGNAL
REFERENCE
VOLTAGE
REGULATOR
INPUT
CONDITIONERS
AMP
ANALOG
TO
DIGITAL
CONVERTER
MICROCOMPUTER
MICROPROCESSOR
MEMORY
MEMORY
MEMORY
OUTPUT
DRIVERS
PROCESSOR
SIGNAL RETURN
PROVIDED
THROUGH
MICROCOMPUTER
5 VREF
LOW VOLTAGE
SIGNAL
THROTTLE PLATE
CLOSED
SIGNAL
RETURN

Fig. 2. Schematic of reference voltage—throttle position sensor shown. (Courtesy of Ford Motor Company)

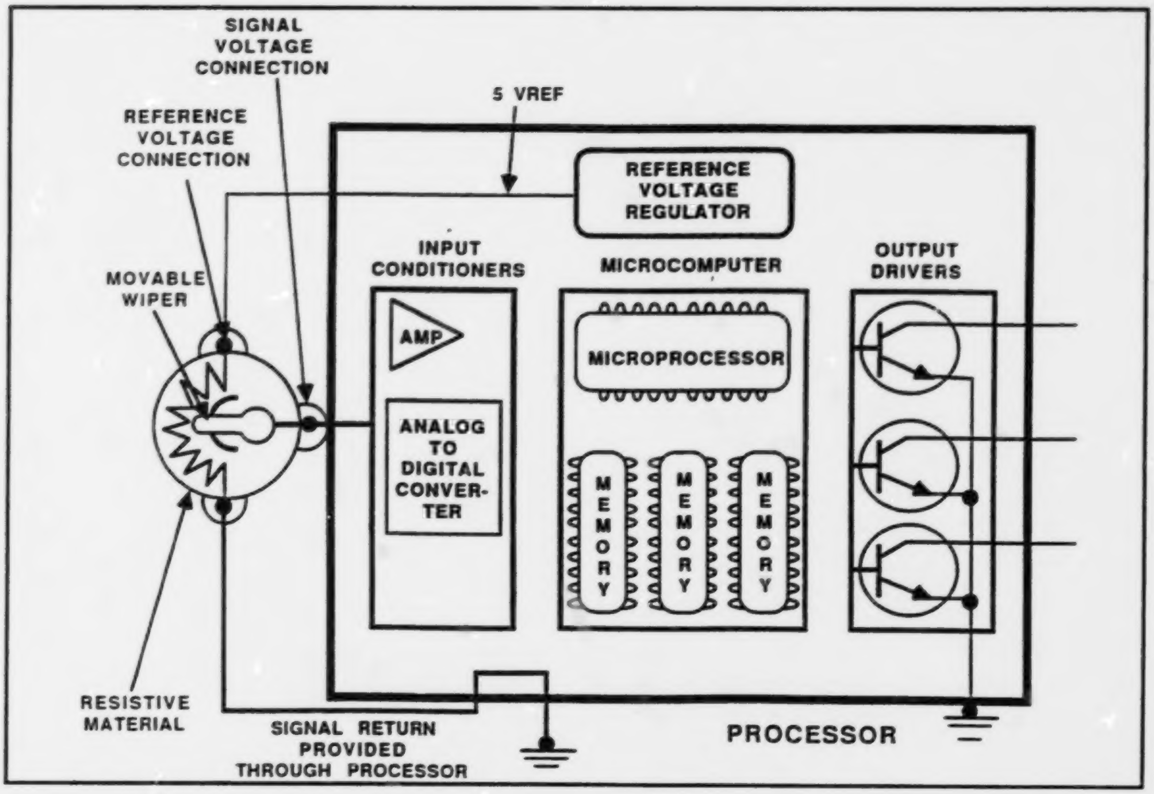

SIGNAL VOLTAGE CONNECTION
REFERENCE VOLTAGE CONNECTION
5 VREF
REFERENCE VOLTAGE REGULATOR
MOVABLE WIPER
INPUT CONDITIONERS
MICROCOMPUTER
OUTPUT DRIVERS
AMP
MICROPROCESSOR
ANALOG TO DIGITAL CONVERTER
MEMORY
MEMORY
MEMORY
RESISTIVE MATERIAL
SIGNAL RETURN PROVIDED THROUGH PROCESSOR
PROCESSOR

Fig. 3. Schematic of rotary potentiometer. (Courtesy of Ford Motor Company)

potentiometer, but all potentiometers will have three connections, with the resistive material connected between two of the connections and the wiper connected to the third.

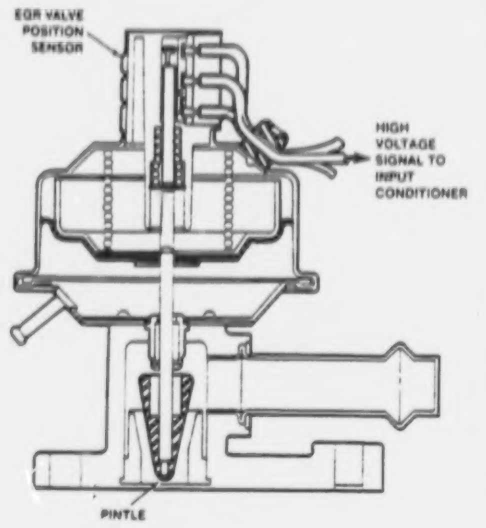
Switches

Sensors that switch ON or OFF to sense position are very common. The limit switches used on the passive seat belt system are one application. Contact switches sensing the position of the clutch and brake pedals are also used. Figure 5 shows a switch which sends a signal to the computer module giving the position of the clutch pedal. This switch indicates that the clutch is either released or in use. When the clutch is released, the switch is open, and the microprocessor will see 5 volts. When the clutch is depressed, the switch is closed, and the microprocessor will see 0 volts. The microprocessor sees 0 volts with the switch closed, since the voltage is dropped across the current limiting resistor shown in the module.

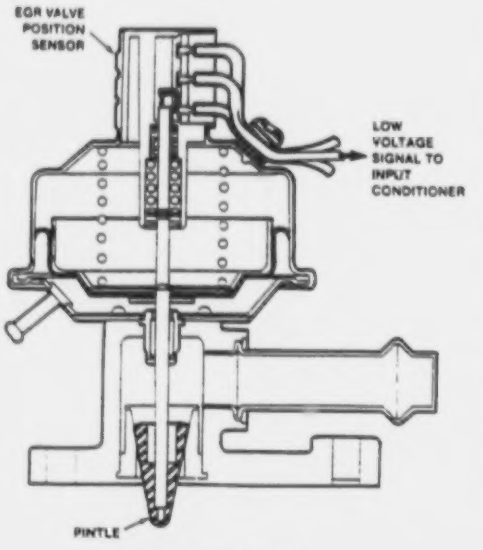
Thermistors

The thermistor is a resistor that changes its resistance with changes in temperature. The thermistor is made from semiconductor material that has a negative temperature coefficient. That is, its resistance will change in the opposite direction to the change in temperature. When the temperature climbs, the thermistor's resistance goes down (fig. 6).

A thermistor has two connections, like any other resistor. When it is used with a computer module, a reference voltage is fed through a current limiting resistor and then through the thermistor to make a voltage divider (fig. 7).


EGR VALVE POSITION SENSOR
HIGH VOLTAGE SIGNAL TO INPUT CONDITIONER
PINTLE

EGR VALVE FULLY OPEN


EGR VALVE POSITION SENSOR
LOW VOLTAGE SIGNAL TO INPUT CONDITIONER
PINTLE

EGR VALVE FULLY CLOSED

Fig. 4. Linear potentiometer converts mechanical motion to a voltage value. (Courtesy of Ford Motor Company)

The cross section of the thermistor shown in figure 7 is typical of the type used to monitor the water temperature in an engine. Notice the sensing element at the tip of the thermistor and the insulated conductors going to the plug that is recessed in the body of the device.

To further illustrate how the thermistor is used by the computer module, figure 8 shows a thermometer indicating a cold engine. This results in a high resistance for the thermistor which forms the voltage divider system discussed earlier. Figure 8 shows the current limiting resistor, which will drop less voltage with a high resistance in the thermistor. The result will be a higher voltage going to the A/D converter shown in the computer module.

When the engine is hot, the resistance as shown in figure 9 will be low. This results in a higher voltage drop across the current limiting resistor and a lower voltage to the A/D converter.

The thermistor is often used to measure engine coolant temperature, air temperature, and sometimes oil temperature. This device only changes resistance and does not generate a voltage.

Piezoelectric Devices

Piezoelectric devices generate a voltage when pressure is applied to the material. The quartz crystal is one of the common materials that will supply a small voltage when pressure is applied (fig. 10). The sensor, using the

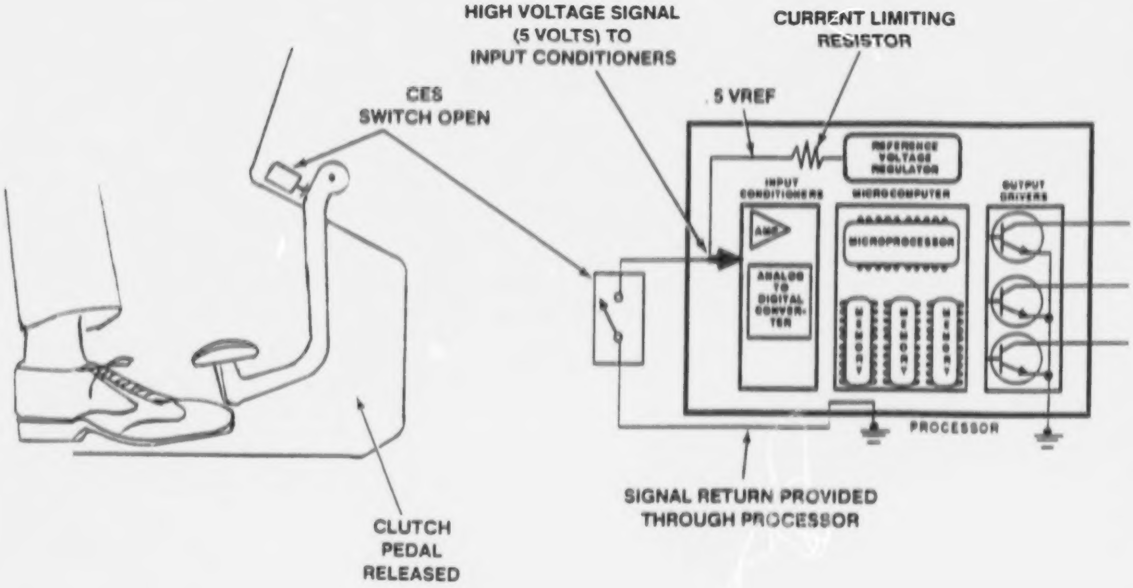

HIGH VOLTAGE SIGNAL (5 VOLTS) TO INPUT CONDITIONERS
CURRENT LIMITING RESISTOR
CES SWITCH OPEN
5 VREF
REFERENCE VOLTAGE REGULATOR
INPUT CONDITIONERS
MICROCOMPUTER
OUTPUT DRIVERS
AMP
MICROPROCESSOR
ANALOG TO DIGITAL CONVERTER
MEMORY
MEMORY
MEMORY
PROCESSOR
SIGNAL RETURN PROVIDED THROUGH PROCESSOR
CLUTCH PEDAL RELEASED

Fig. 5. Clutch engaged switch open. (Courtesy of Ford Motor Company)

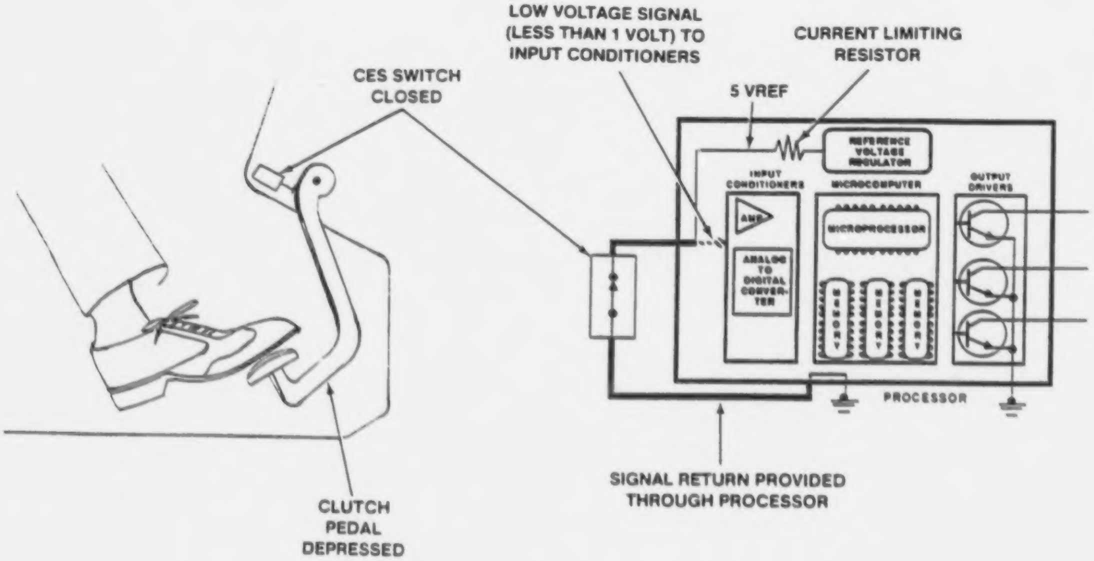

LOW VOLTAGE SIGNAL (LESS THAN 1 VOLT) TO INPUT CONDITIONERS
CURRENT LIMITING RESISTOR
CES SWITCH CLOSED
5 VREF
REFERENCE VOLTAGE REGULATOR
INPUT CONDITIONERS
MICROCOMPUTER
OUTPUT DRIVERS
AMP
MICROPROCESSOR
ANALOG TO DIGITAL CONVERTER
MEMORY
MEMORY
MEMORY
PROCESSOR
SIGNAL RETURN PROVIDED THROUGH PROCESSOR
CLUTCH PEDAL DEPRESSED

Fig. 6. Clutch engaged switch closed. (Courtesy of Ford Motor Company)

piezoelectric crystal, can be made by sandwiching the crystal between two conductors.

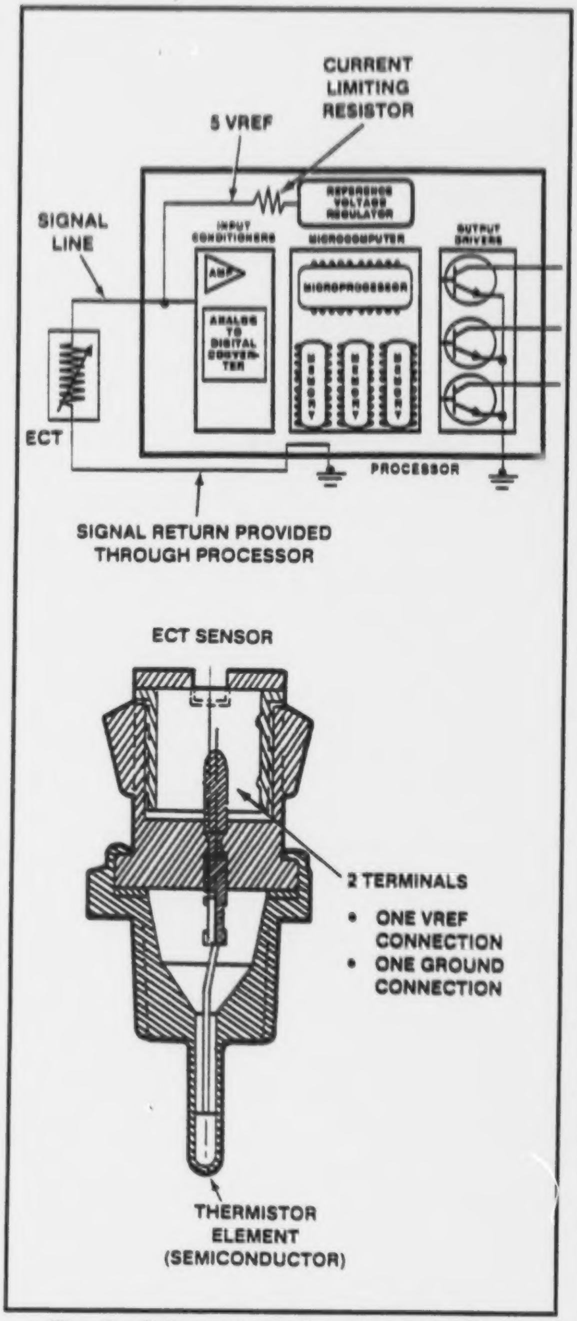

CURRENT
LIMITING
RESISTOR
5 VREF
SIGNAL
LINE
ECT
PROCESSOR
SIGNAL RETURN PROVIDED
THROUGH PROCESSOR
ECT SENSOR
2 TERMINALS
• ONE VREF
CONNECTION
• ONE GROUND
CONNECTION
THERMISTOR
ELEMENT
(SEMICONDUCTOR)

Fig. 7. Schematic of thermistor circuit—engine coolant temperature sensor shown. (Courtesy of Ford Motor Company)

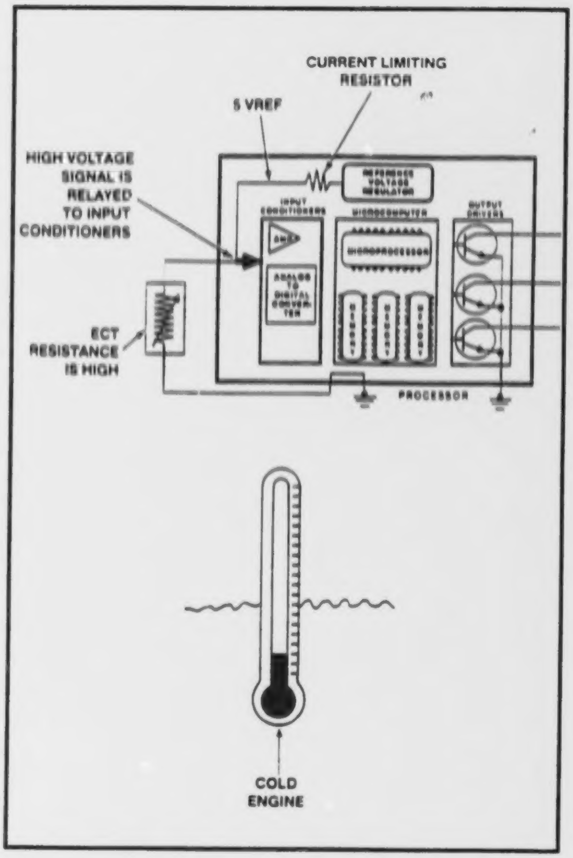

CURRENT LIMITING
RESISTOR
5 VREF
HIGH VOLTAGE
SIGNAL IS
RELAYED
TO INPUT
CONDITIONERS
ECT
RESISTANCE
IS HIGH
PROCESSOR
COLD
ENGINE

Fig. 8. Engine coolant temperature sensor relays high voltage when engine is cold. (Courtesy of Ford Motor Company)

Piezoelectric devices are used to make sensors to detect engine knock. These knock sensors are mounted on the engine block at a location where there will be a strong vibration for the sensor to detect (fig. 11). The knock sensor is tuned to the type of vibration that comes from engine knock since a typical engine will have a lot of other types of vibration.

Oxygen Sensor

The oxygen sensor is used to detect the amount of oxygen left in the exhaust gases after combustion. This information is used by the computer to

adjust the air-fuel ratio. The oxygen sensor provides feedback to the computer on maintaining the proper air-fuel mixture for proper combustion. This results in fewer harmful emissions.

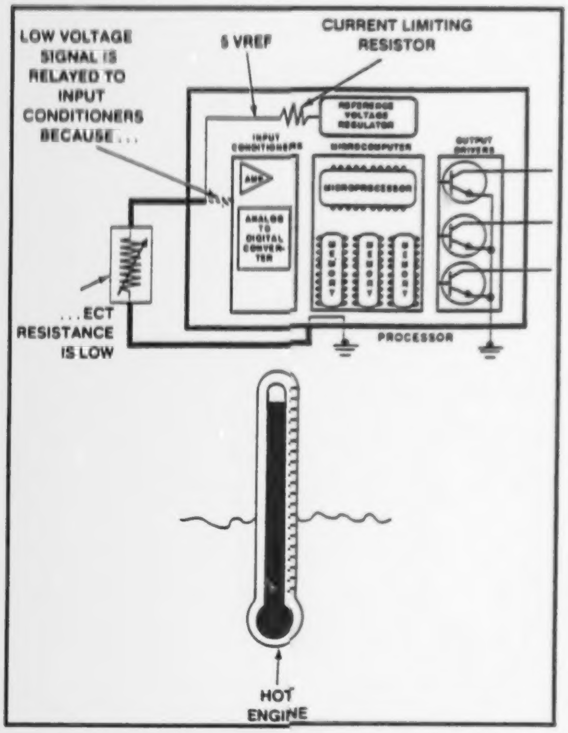

LOW VOLTAGE SIGNAL IS RELAYED TO INPUT CONDITIONERS BECAUSE . . .
5 VREF
CURRENT LIMITING RESISTOR
REFERENCE VOLTAGE REGULATOR
INPUT CONDITIONERS
MICROCOMPUTER
OUTPUT DRIVERS
AMP
MICROPROCESSOR
ANALOG TO DIGITAL CONVERTER
MEMORY
MEMORY
MEMORY
. . . ECT RESISTANCE IS LOW
PROCESSOR
HOT ENGINE

Fig. 9. Engine coolant temperature sensor relays low voltage when engine is hot. (Courtesy of Ford Motor Company)

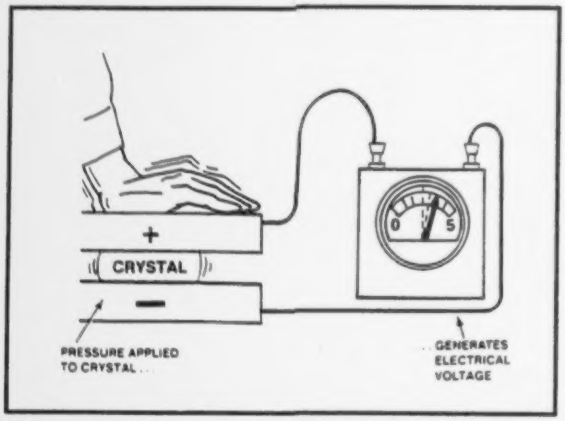

+
CRYSTAL
−
0
5
PRESSURE APPLIED TO CRYSTAL . . .
. . GENERATES ELECTRICAL VOLTAGE

Fig. 10. Piezoelectric sensor construction and operation. (Courtesy of Ford Motor Company)

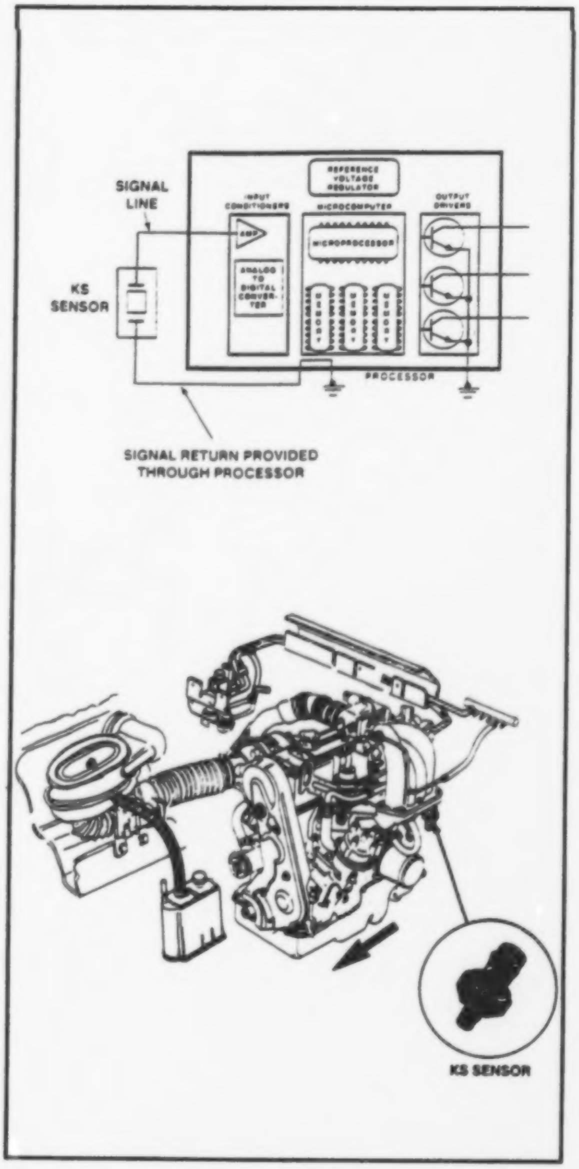

SIGNAL LINE
KS SENSOR
REFERENCE VOLTAGE REGULATOR
INPUT CONDITIONERS
MICROCOMPUTER
OUTPUT DRIVERS
AMP
MICROPROCESSOR
ANALOG TO DIGITAL CONVERTER
MEMORY
MEMORY
MEMORY
PROCESSOR
SIGNAL RETURN PROVIDED THROUGH PROCESSOR
KS SENSOR

Fig. 11. Schematic of typical piezoelectric sensor circuit. (Courtesy of Ford Motor Company)

The zirconium dioxide oxygen sensor (fig. 12) will produce a varying voltage that is mostly low when there is a high concentration of oxygen in the exhaust gases. With a low concentration of oxygen, the average voltage output from the sensor will be high.

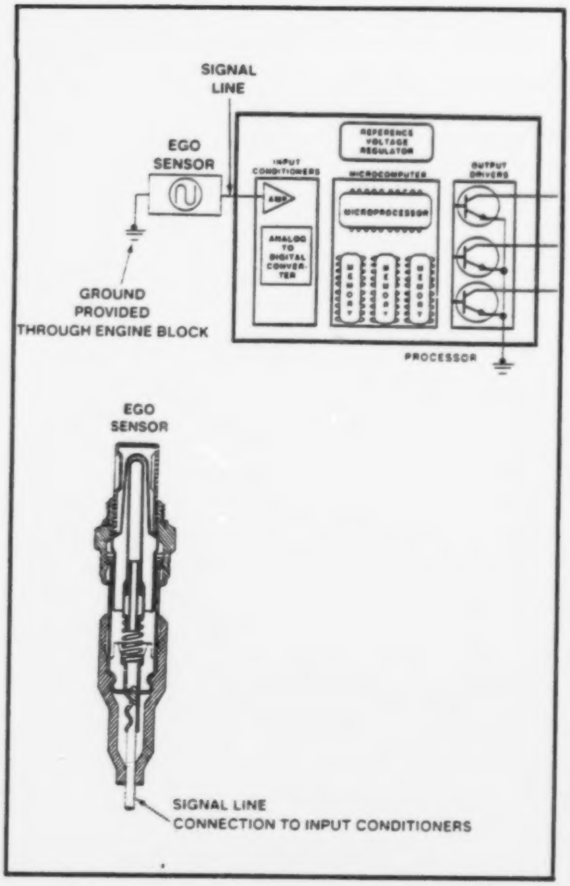

SIGNAL
LINE
EGO
SENSOR
INPUT
CONDITIONERS
AMP
ANALOG
TO
DIGITAL
CONVER-
TER
REFERENCE
VOLTAGE
REGULATOR
MICROCOMPUTER
MICROPROCESSOR
MEMORY
MEMORY
MEMORY
OUTPUT
DRIVERS
PROCESSOR
GROUND
PROVIDED
THROUGH ENGINE BLOCK
EGO
SENSOR
SIGNAL LINE
CONNECTION TO INPUT CONDITIONERS

Fig. 12. Schematic of exhaust gas oxygen sensor circuit. (Courtesy of Ford Motor Company)

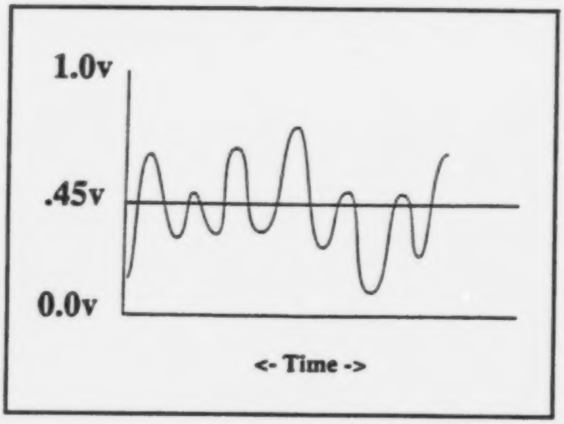


Fig. 13. Normal O₂ sensor voltage. (Courtesy of Ford Motor Company)

The voltage can vary from 0 to 1 volt, but usually averages from 400 to 600 mV. If an oscilloscope is used to monitor the voltage output from a oxygen sensor with a normal oxygen concentration, the result would look like figure 13. Notice how the voltage varies around 450 mV.

You can use your digital voltmeter to observe the rapid changing of voltage from a working oxygen sensor. Do not use a low impedance meter to measure the voltage from an oxygen sensor. The low impedance meter will draw too much current and damage the sensor.

If the engine is running lean or has too much air for the amount of fuel, voltage from an oxygen sensor could look like figure 14. Here the voltage is varying around 200 mV instead of the 450 mV for an engine with the proper air-fuel mixture.

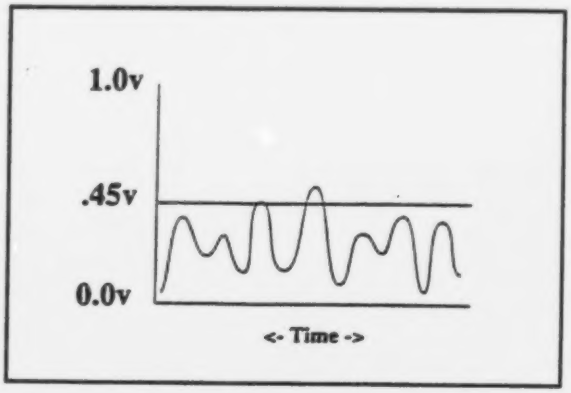


Fig. 14. Lean O₂ sensor voltage. (Courtesy of Ford Motor Company)

When an oscilloscope is used to look at the voltage coming from an oxygen sensor on an engine running rich, it could look like figure 15. This shows the voltage varying around 700 mV, and it only crosses the 450 mV line twice.

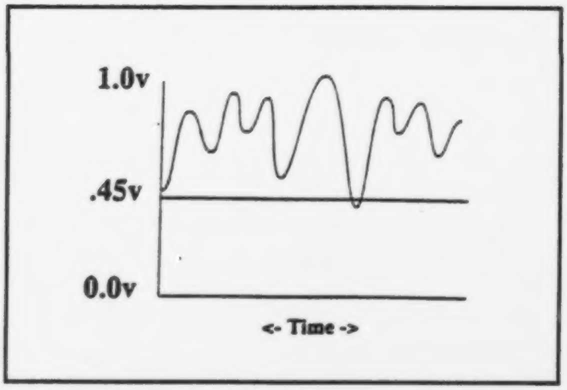


Fig. 15. Rich O_2 sensor voltage. (Courtesy of Ford Motor Company)

The computer will normally store a fault code for a rich or lean condition coming from the oxygen sensor. You then have to determine what specifically has caused the problem.

Figure 16 should help in understanding how the oxygen sensor works. The active part of the sensor is the zirconium dioxide which has a coating of platinum on both sides. Platinum is a metal that strongly resists any corrosion or contamination which would reduce the effectiveness of the sensor. The difference in the amount of oxygen on either side of the zirconium dioxide will cause a voltage to be built up between the platinum coatings on each side of the zirconium dioxide.

The drawing of the body of the sensor shows how the outside air enters the sensor from the back and the exhaust air enters the sensor from the tip. If there is anything blocking either the outside air or the exhaust air, the sensor will not work.

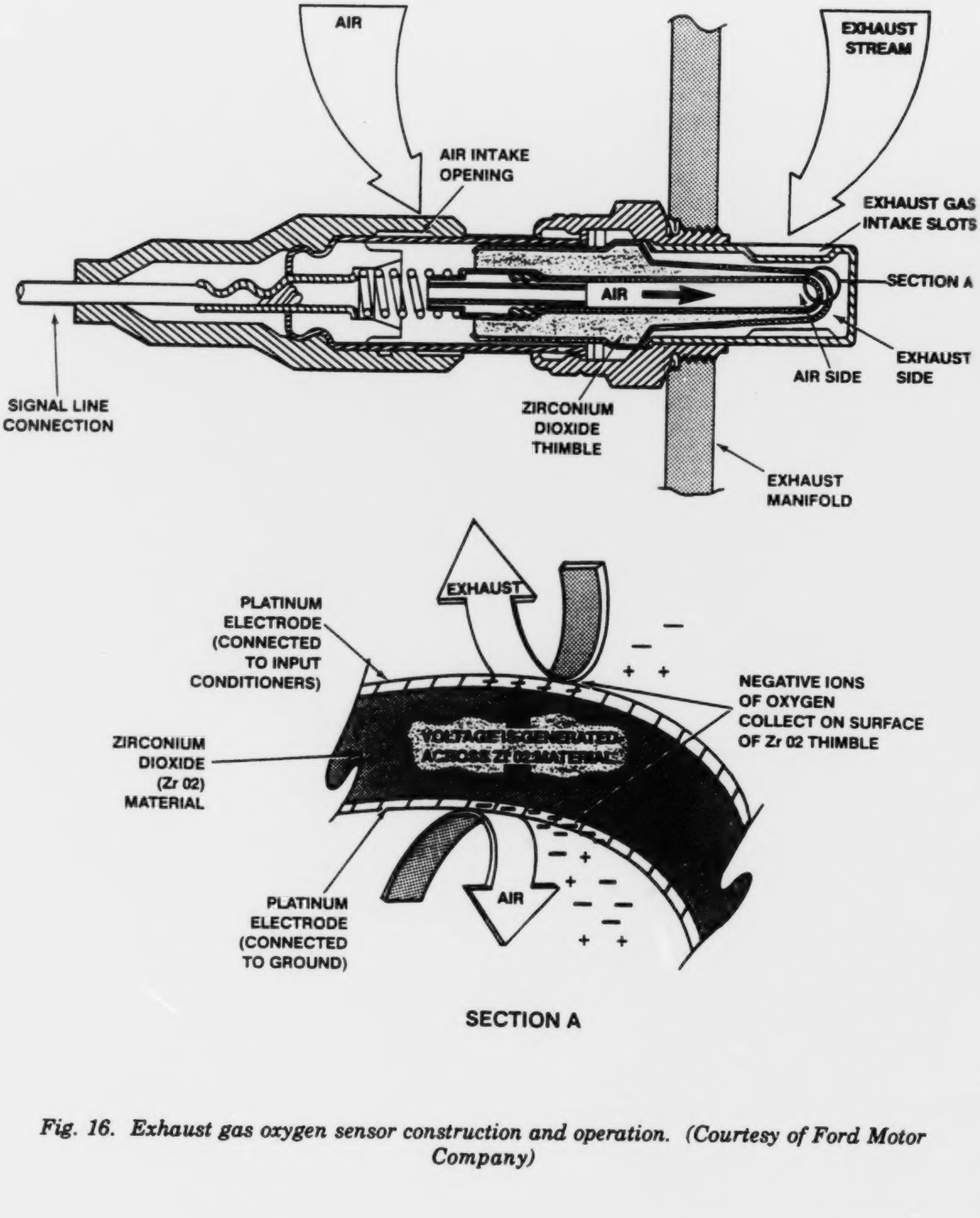
The oxygen sensor must be at or above 600°F before it starts to operate. Some sensors are electrically heated to bring them up to operating temperature quickly. The computer will examine the inputs from the oxygen sensor and other inputs to determine if it is going to include the oxygen sensor inputs or ignore them. When the sensor is ignored, the computer is controlling the air-fuel mixture, open loop. What this means is that the feedback loop is open or there is no feedback to tell the computer how to adjust the air-fuel mixture. This can result in a poor response from the engine or drivability problems.

The oxygen sensor can fail or lose some sensitivity as a result of contamination, often from poor quality gasoline, or simply become slow in its response. A slow sensor will not usually cause a trouble code, but can cause drivability problems. This type of problem can be difficult for the technician to diagnose. Technicians should try to develop some familiarity with the response from known good sensors in different types of cars so they can recognize a slow or weak sensor.

If a too rich condition is left too long, the carbon in the exhaust can coat the sensor, causing it to become slow or fail altogether. Silica from RTV gasket materials can coat the sensor and result in a lean mixture or sensor failure. If leaded gasoline is used, the lead additives will coat the sensor giving it a glazed appearance. If the gasoline has large quantities of methanol added to it, this will coat the sensor as well. Oil entering the exhaust gases will coat the sensor and cause it to fail, and antifreeze will leave a whitish deposit on the sensor, usually resulting in failure of the sensor.

Magnetic Sensors

Magnetic sensors are made using either the Hall effect technology or


AIR
EXHAUST STREAM
AIR INTAKE OPENING
EXHAUST GAS INTAKE SLOTS
AIR
SECTION A
EXHAUST SIDE
AIR SIDE
SIGNAL LINE CONNECTION
ZIRCONIUM DIOXIDE THIMBLE
EXHAUST MANIFOLD
EXHAUST
PLATINUM ELECTRODE (CONNECTED TO INPUT CONDITIONERS)
NEGATIVE IONS OF OXYGEN COLLECT ON SURFACE OF Zr 02 THIMBLE
ZIRCONIUM DIOXIDE (Zr 02) MATERIAL
VOLTAGE IS GENERATED ACROSS Zr 02 MATERIAL
PLATINUM ELECTRODE (CONNECTED TO GROUND)
AIR

SECTION A

Fig. 16. Exhaust gas oxygen sensor construction and operation. (Courtesy of Ford Motor Company)

magnetic pickup technology. The primary purpose of magnetic sensors is to detect the position of an automotive component. Magnetic pickups are used in solid-state ignitions to detect the position of the distributor shaft, and sensors are used to detect the orientation of the crankshaft.

The magnetic pickup type of sensor consists of a coil of wire with a permanent magnetic core (fig. 17). This sensor will generate a voltage when the magnetic lines of flux are disturbed.

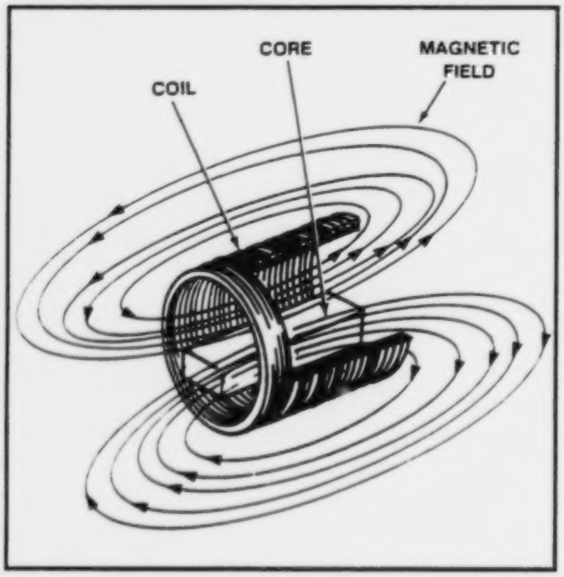

CORE
MAGNETIC FIELD
COIL

Fig. 17. Magnetic pickup construction. (Courtesy of Ford Motor Company)

The signal voltage generated by the magnetic pickup is sent to the computer, as shown in figure 18. The computer will condition the signal from the pickup and provide a pulse of the proper voltage and duration for the digital circuits in the computer to recognize and process.

One of the common applications for a magnetic pickup sensor is the crankshaft position sensor. The magnetic sensor used here has a magnetic pickup assembly at the tip of the sensor. The sensor is usually mounted on the engine block where it will have access to the edge of the pulse ring (fig. 19).

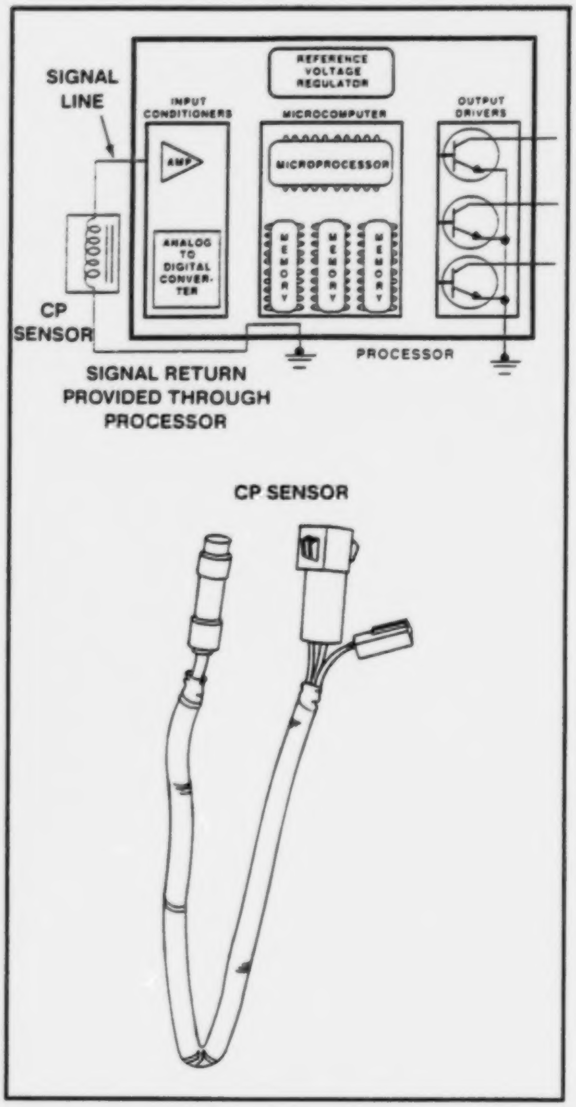

SIGNAL LINE
REFERENCE VOLTAGE REGULATOR
INPUT CONDITIONERS
MICROCOMPUTER
OUTPUT DRIVERS
AMP
MICROPROCESSOR
ANALOG TO DIGITAL CONVERTER
MEMORY
MEMORY
MEMORY
CP SENSOR
PROCESSOR
SIGNAL RETURN PROVIDED THROUGH PROCESSOR
CP SENSOR

Fig. 18. Schematic of a magnetic pickup circuit–crankshaft position sensor shown. (Courtesy of Ford Motor Company)

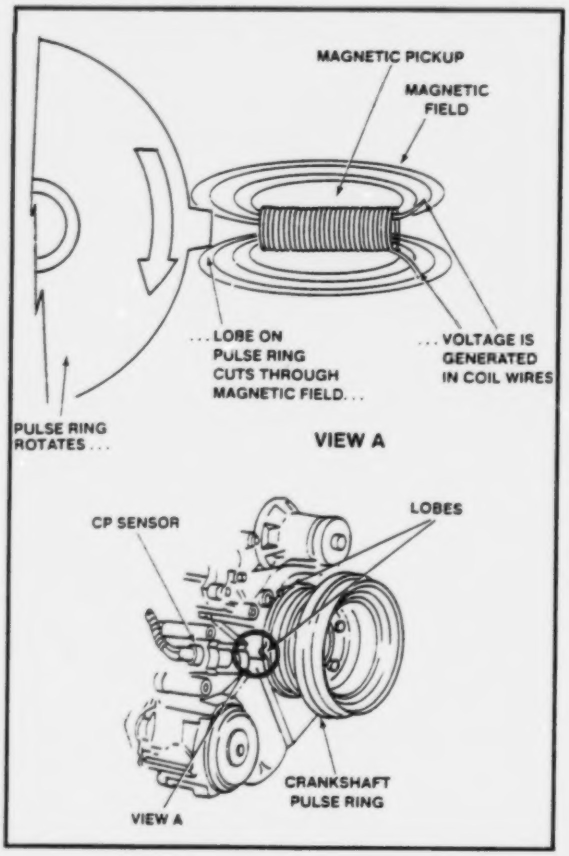

MAGNETIC PICKUP
MAGNETIC FIELD
...LOBE ON PULSE RING CUTS THROUGH MAGNETIC FIELD...
...VOLTAGE IS GENERATED IN COIL WIRES
PULSE RING ROTATES...
VIEW A
CP SENSOR
LOBES
CRANKSHAFT PULSE RING
VIEW A

Fig. 19. Crankshaft position sensor construction. (Courtesy of Ford Motor Company)

As the metal lobe on the pulse ring passes the sensor, it disturbs the magnetic field, which generates a voltage in the coil. This voltage is sent to the computer.

The other type of magnetic sensor is the Hall effect sensor. This type uses solid-state electronics to sense the position of a magnetic field. Most automotive manufacturers are using the Hall effect sensors for the ignition pickup device in their solid-state ignition systems.

A typical sensor arrangement is shown in figure 20. The rotary vane cup shown has a set of vanes around its edge. There is one vane for each engine cylinder. The Hall effect switch assembly contains the solid-state Hall effect device on one side and a permanent magnet on the other.

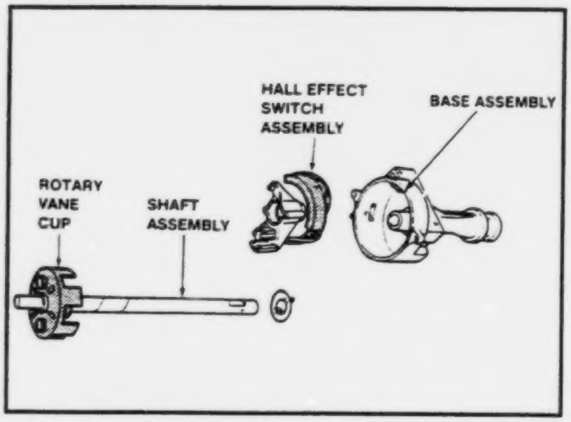

HALL EFFECT SWITCH ASSEMBLY
BASE ASSEMBLY
ROTARY VANE CUP
SHAFT ASSEMBLY

Fig. 20. Profile ignition pickup sensor location/construction. (Courtesy of Ford Motor Company)

The vanes on the cup are designed to pass between the Hall effect switch and the permanent magnet (fig. 21). When a vane is between the magnet and the switch, the magnetic lines of force are directed through the vane and back to the magnet. When the vane is not between the magnet and switch, the magnetic lines of force pass through the Hall effect switch (fig. 22).

The Hall effect switch operates by sensing the presence of a magnetic field. When a magnetic field is present, a voltage is induced in the semiconductor material at right angles to the flow of current. The Hall effect device has to have current flow to operate. There are usually three leads coming from the Hall effect switch. One lead is a ground lead, one lead will supply the device with 12 volts from the battery, and the other lead will provide the path for the voltage signal to the computer.

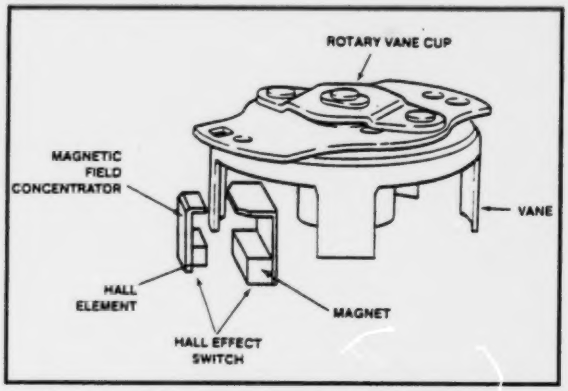

ROTARY VANE CUP
MAGNETIC FIELD CONCENTRATOR
VANE
HALL ELEMENT
MAGNET
HALL EFFECT SWITCH

Fig. 21. Rotary vane cup, Hall effect switch. (Courtesy of Ford Motor Company)

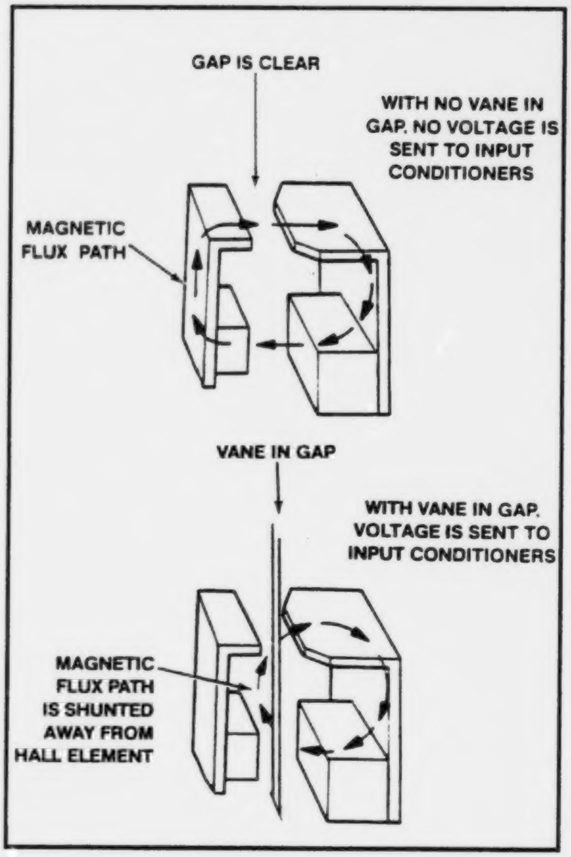

GAP IS CLEAR
WITH NO VANE IN GAP, NO VOLTAGE IS SENT TO INPUT CONDITIONERS
MAGNETIC FLUX PATH
VANE IN GAP
WITH VANE IN GAP, VOLTAGE IS SENT TO INPUT CONDITIONERS
MAGNETIC FLUX PATH IS SHUNTED AWAY FROM HALL ELEMENT

Fig. 22. Hall effect switch operation. (Courtesy of Ford Motor Company)

Some manufacturers use a variety of other sophisticated methods to sense position, temperature, and pressure. One method of measuring pressure is to use a diaphragm that will act as a capacitor and allow the position of the diaphragm to change the frequency of a circuit. This type of sensor can be difficult to check with an ordinary meter. The oscilloscope can be used to detect the frequency changes with movement of the diaphragm.

Exercise

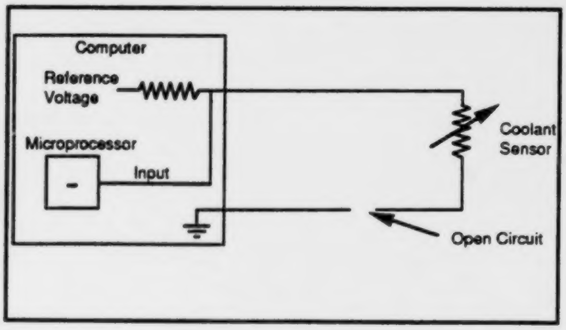

Computer
Reference Voltage
Microprocessor
-
Input
Coolant Sensor
Open Circuit

Fig. 23. Open circuit

1. If the reference voltage is 6 volts in figure 23, the current limiting resistor is 100 kΩ, and the thermistor is 50 kΩ, what is the voltage that is sent to the microprocessor?

2. Using the values from question 1, what would the voltage be, referenced to ground, at the bottom of the thermistor?

3. If the current limiting resistor in figure 24 is 50 kΩ, the thermistor is 30 kΩ, and the reference voltage is 12 volts, what is the voltage sent to the microprocessor?

4. When the short in figure 24 is repaired, what voltage will be sent to the microprocessor, using the values given in question 3?

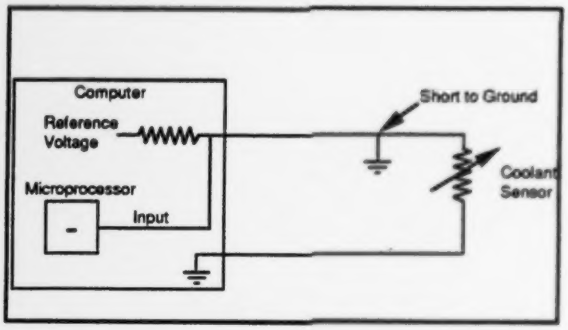

Computer
Reference Voltage
Microprocessor
Input
Short to Ground
Coolant Sensor

Fig. 24. Shorted circuit

5. If a thermistor with a positive temperature coefficient goes from 80°F to 150°F, what will happen to the resistance of the device?
6. What is the minimum operating temperature of an oxygen sensor?

F-1 Automotive Sensors

Laboratory Experiment

Essential Elements: (gg)(1, 2, and 4)

Objective

This lab will allow the student to examine how a variable resistance sensor supplies a voltage signal to the computer.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 10 kΩ resistor
1 variable resistor (10 kΩ pot)
1 DVOM

Procedure

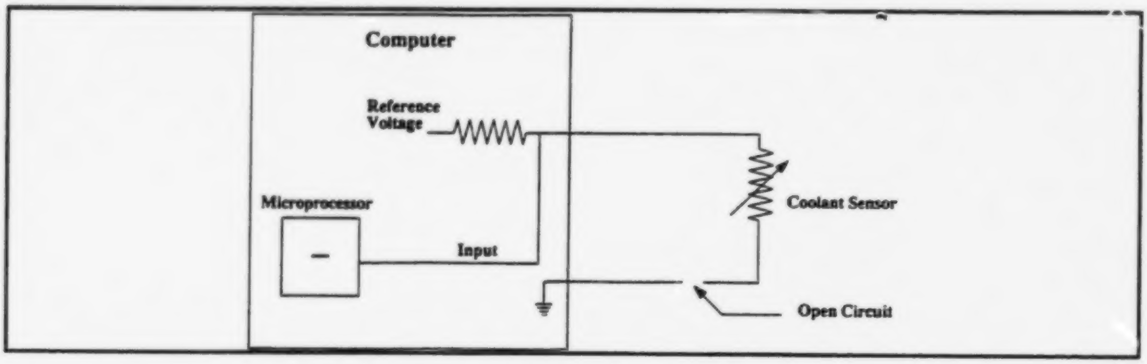


Fig. 1. Two-wire coolant sensor circuit

Figure 1 shows a coolant sensor resistance or thermistor with an arrow through it to indicate that its resistance will change. You will use the potentiometer to simulate the thermistor. Simply connect to the center terminal and the one outside terminal to simulate the two-terminal thermistor. The fixed resistor or current limiting resistor will be the 10 kΩ, and the voltage reference will be the 6-volt battery pack that you have.

1. Draw the circuit, on a separate piece of paper, that you will build to simulate the circuit in figure 1.

2. Connect your DVOM to the two terminals on the pot that you plan to use, and adjust the resistance of the pot until your DVOM reads 1,000 Ω.

3. Calculate the voltage that will be sent to the computer with the 1,000 Ω thermistor, the 10 kΩ current limiting resistor, and the 6-volt reference source.

4. Build the circuit and measure the voltage that would be sent to the computer. If the measured voltage is more than 10% different than your calculated voltage, recheck your work.

5. Redo steps 2, 3, and 4 using 2,000 Ω, 2,500 Ω, 3,000 Ω, 3,500 Ω, and 4,000 Ω. Recheck your calculations if your calculated voltages are more than 10% different than your measured voltages.

F-2

Engine Fuel Delivery Systems

Essential Elements: (gg)(1, 2, 4, and 5)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals and operation of:

- *automotive sensors*
- *the gasoline fuel delivery system*
- *the electronic ignition system*
- *the emission control system*
- *the diesel fuel delivery and control system*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how the computer controls the delivery of fuel to the injectors*
- *explain how the computer learns and corrects for changes in the engine*

Computer Control of the Fuel System

Both the government and automobile customers have demanded that manufacturers build cars with low exhaust emissions and efficient use of the gasoline—or high mileage cars. To achieve this, the fuel has to be burned very efficiently. The result is a computer-controlled fuel and air delivery system using many sensors to monitor and correct the air-fuel ratio. Figure 1 shows a typical computer that is used to control the fuel system with its sensor inputs and its controlled output devices.

Computer control of the fuel and air delivery system in an automobile involves a fuel injection system. The old type of carburetor does not need electronic controls. The electronically controlled fuel injection system involves three basic areas: air intake, fuel delivery, and electronic control.

The air intake into each of the injector systems is handled like a carburetor would handle the air. The injector (fig. 2) sprays the fuel into the incoming air. This air-fuel mixture then passes the throttle plate or into the combustion chamber. A mechanical fuel pressure regulator smooths out any of the fluctuations in fuel pressure before they get to the injector.

The difference between the fuel injected system and a carbureted system is the method of fuel delivery. A carbureted system will have a throat that gets smaller, reducing the air pressure and drawing out the fuel. The injected

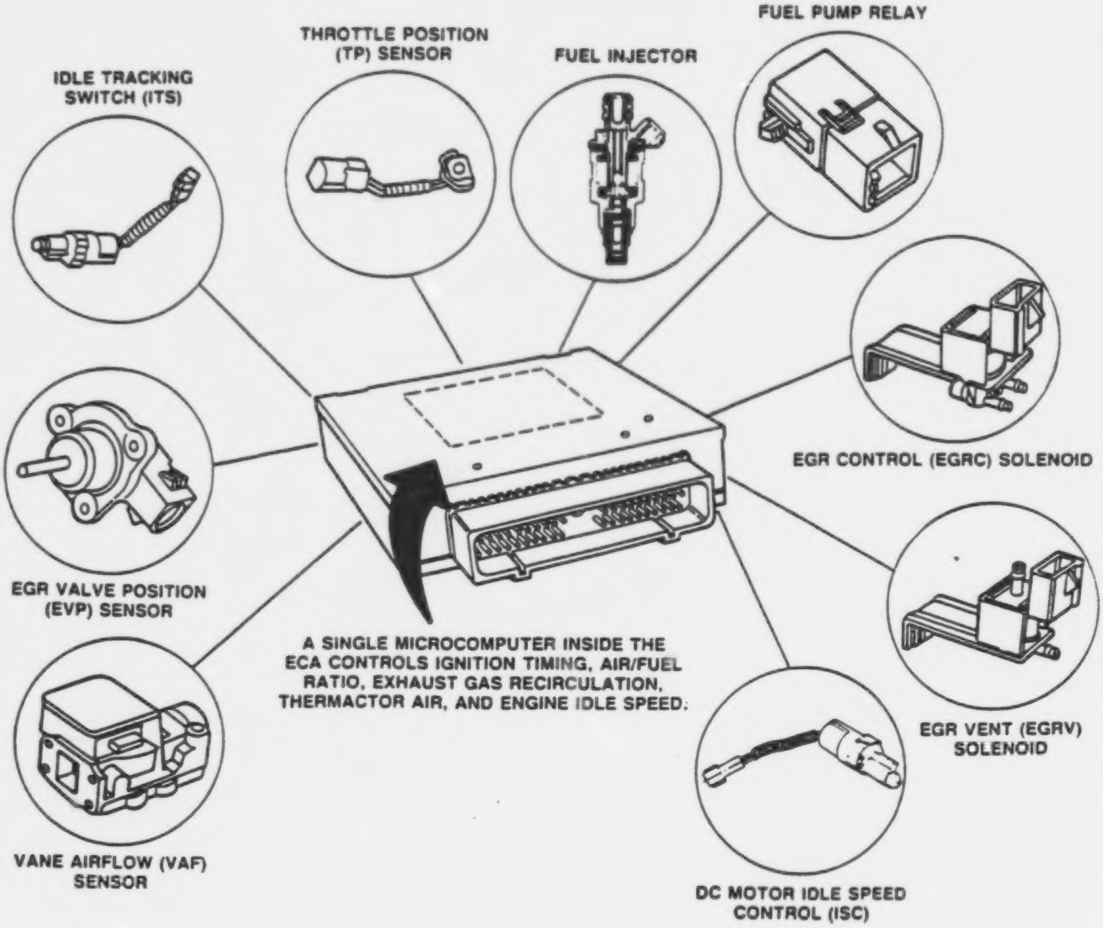

IDLE TRACKING SWITCH (ITS)
THROTTLE POSITION (TP) SENSOR
FUEL INJECTOR
FUEL PUMP RELAY
EGR CONTROL (EGRC) SOLENOID
EGR VALVE POSITION (EVP) SENSOR
A SINGLE MICROCOMPUTER INSIDE THE ECA CONTROLS IGNITION TIMING, AIR/FUEL RATIO, EXHAUST GAS RECIRCULATION, THERMACTOR AIR, AND ENGINE IDLE SPEED.
EGR VENT (EGRV) SOLENOID
VANE AIRFLOW (VAF) SENSOR
DC MOTOR IDLE SPEED CONTROL (ISC)

Fig. 1. Electronic control assembly. (Courtesy of Ford Motor Company)

system sprays fuel into the intake air and does not need the restricted opening to decrease the air pressure. Also, the fuel injected method will have injectors in the throttle body or at each cylinder, while the carbureted method will use a common carburetor for more then one cylinder.

Figure 3 shows a fuel injection system used by Ford, which they call their multipoint fuel injection system. Notice the common air intake on the top of the engine. Each of the four cylinders shown has an injector. An air bypass valve assembly controls the idle speed of the engine.

Most fuel injection systems use an electric fuel pump to draw fuel from the fuel tank. In some cases, there may be a low-pressure pump in the fuel tank and a high-pressure pump in the line to send the fuel at a high pressure to the engine. These systems will have around 40 psi of pressure in the lines.

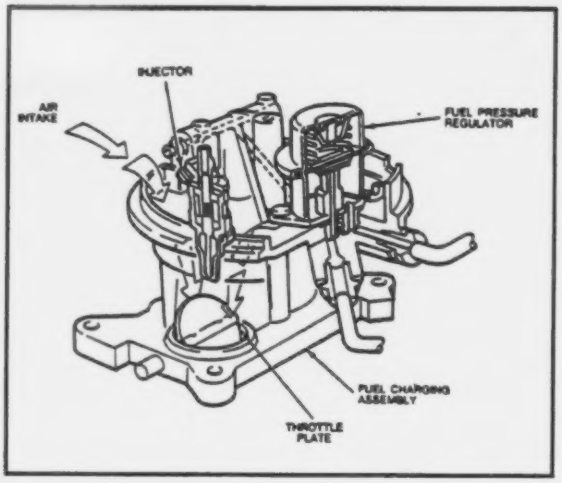

INJECTOR
AIR INTAKE
FUEL PRESSURE REGULATOR
FUEL CHARGING ASSEMBLY
THROTTLE PLATE

Fig. 2. High-pressure CFI air intake. (Courtesy of Ford Motor Company)

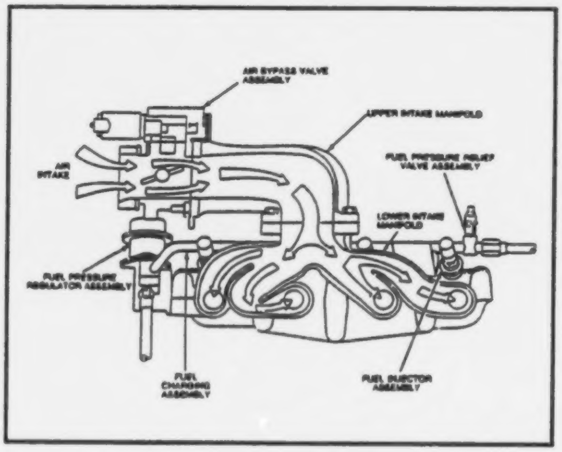

AIR BYPASS VALVE ASSEMBLY
UPPER INTAKE MANIFOLD
AIR INTAKE
FUEL PRESSURE RELIEF VALVE ASSEMBLY
LOWER INTAKE MANIFOLD
FUEL PRESSURE REGULATOR ASSEMBLY
FUEL CHARGING ASSEMBLY
FUEL INJECTOR ASSEMBLY

Fig. 3. Multiport fuel injection air intake. (Courtesy of Ford Motor Company)

The fuel system will have one line from the fuel tank to supply the fuel, and return lines to bring back excessive fuel supplied by the pump (fig. 4).

The primary output from the computer controlling the fuel delivery system is to control the amount of fuel delivered by the injectors. The air is controlled by the driver with the accelerator pedal. The amount of air is monitored by the computer, and the oxygen level in the exhaust gases also gives the computer feedback on the air-fuel ratio. The computer makes adjustments by controlling the amount of fuel delivered to the engine from the injectors.

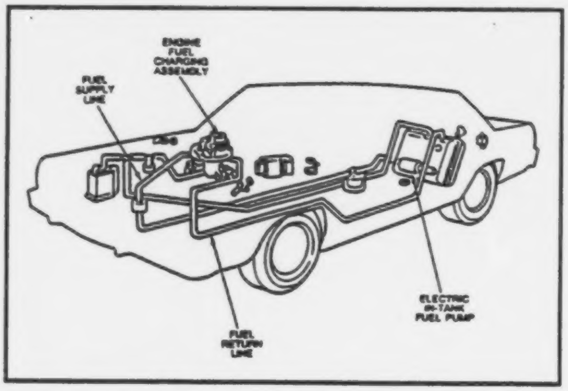

ENGINE FUEL CHARGING ASSEMBLY
FUEL SUPPLY LINE
ELECTRIC IN-TANK FUEL PUMP
FUEL RETURN LINE

Fig. 4. Typical CFI fuel injection system. (Courtesy of Ford Motor Company)

The injectors are electromechanical devices that meter and atomize the fuel delivered to the engine. Figure 5 shows the body of an injector with the solenoid-actuated pintle and needle valve assembly. When the injector receives an electrical pulse, the solenoid moves, causing the pintle to move inward off its seat. This allows fuel to flow through the orifice. The orifice is fixed in its size and shape, so the amount of fuel per second that will flow through the orifice is fixed. The computer controls the amount of fuel by varying the length of the pulse sent to the injector.

The Electronic Control Assembly

The ECA, or electronic control assembly (fig. 6), consists of a microprocessor, memory devices, A/D converter, voltage source, and other signal processing circuits. The ECA supplies the reference voltage for the thermistors and potentiometers and reads the return signal voltage to determine the status of the engine. This reference voltage is always lower than the 12-volt battery voltage. In many systems, the reference voltage will be 5 volts since this is the common voltage for computer circuits.

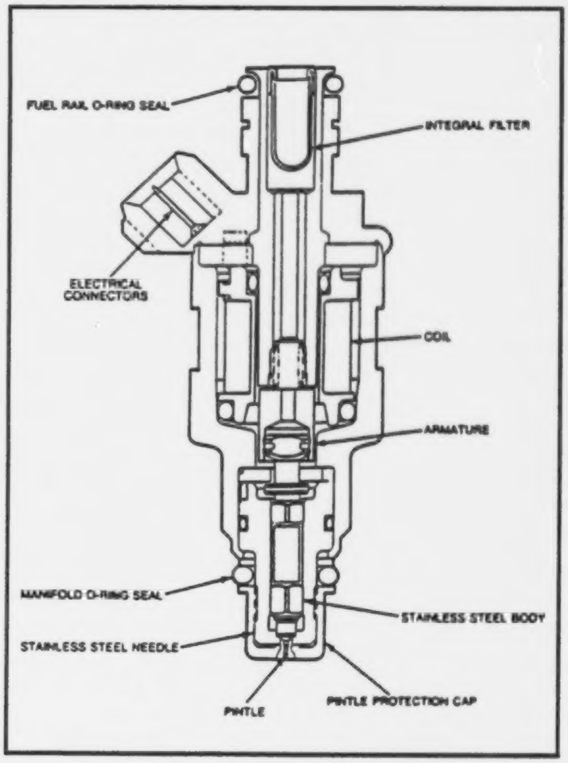


Fig. 5. Typical multiport fuel injector. (Courtesy of Ford Motor Company)

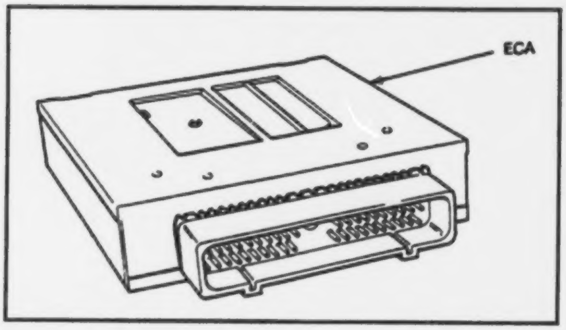


Fig. 6. Electronic control assembly. (Courtesy of Ford Motor Company)

One of the inputs to the ECA comes from the oxygen sensor. The oxygen sensor has to reach a temperature of 600°F before it can start to send data on the oxygen content of the exhaust gases. This is the only sensor that measures the effect of the changes made to the air-fuel ratio by the ECA. When the oxygen sensor is operating and sending data to the ECA and the ECA is using this data, we have a loop that includes the oxygen sensor. This condition is called *closed loop* operation. The ECA is operating *open loop* when it is not receiving or not using the data from the oxygen sensor.

The ECA will operate open loop during the time that the oxygen sensor is warming up, when the engine is cold, or during wide-open throttle condition. During the closed loop condition, the ECA will sample the data from the oxygen sensor. If the oxygen content is too low, it will reduce the length of the pulse sent to the injectors, reducing the quantity of fuel sent into the cylinders in each burst. By reducing the quantity of fuel available to burn, less oxygen is needed and the ratio of fuel to air will be more correct.

The other engine sensor inputs that are necessary for the ECA to correctly send the right pulse to the injectors are crankshaft position and rpm sensor, intake air temperature and intake airflow sensor, engine coolant temperature sensor, EGR (exhaust gas recirculation) flow rate sensor, throttle position sensor, and the manifold absolute pressure and/or barometric absolute pressure sensors. Some fuel injection systems do not need all of these sensors for normal operation.

ECA Strategy

The ECA (computer) has a set of instructions called the software that is stored in ROM and the data that is stored in RAM. The software or set of instructions includes all of the formulas for determining the necessary output based on the particular inputs. This set of instructions cannot be changed and is not lost when power is interrupted to the ECA. The software includes calibration values that are part of the instructions and are used to make the decisions controlling the fuel delivery. These calibration values include the scalars, functions, and tables, which are stored in ROM and are designed by the manufacturer for that particular car.

A *scalar* is a number that has a label. The scalar for the maximum engine rpm could be REVLIM = 6000. This scalar states that the maximum engine rpm is 6,000. A *function* is a mathematical set of values that can be displayed as a graph (fig. 7).

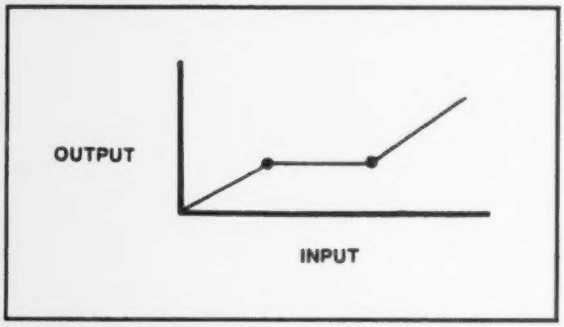


Fig. 7. Function. (Courtesy of Ford Motor Company)

A *table* is a set of values that the computer uses to take two different inputs and solve for an output. Tables can be illustrated as shown in figure 8.

In order to understand how the scalar, functions, and tables are used by the ECA, we need to examine the overall strategy of the computer. To properly control the engine, maintain low emissions, good fuel mileage and good drivability, the ECA must respond to external inputs quickly and perform housekeeping duties as needed. *Housekeeping duties* for a computer are routine repetitive tasks that always need to be done.

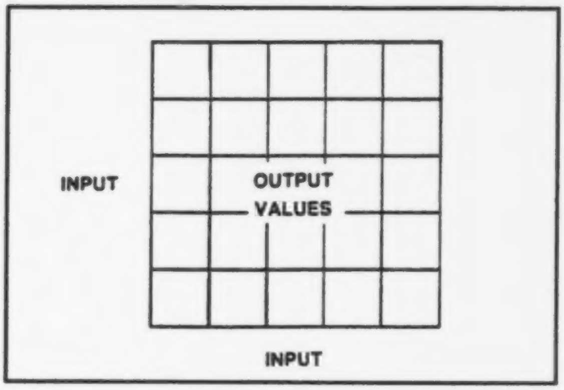


Fig. 8. Table. (Courtesy of Ford Motor Company)

The ECA will accomplish these tasks by dividing the work into two sections, called foreground and background (fig. 9). The foreground functions are the instructions that take priority in the control of the engine. The background handles the low priority items. Notice that the foreground manager part of the ECA handles the injectors (INJ'S), shown as "OUTPUTS (CRITICAL)."

The calibration values consisting of scalars, functions, and tables, mentioned earlier, are used by the ECA in many different ways. Under wide open throttle conditions, the ECA is operating open loop, which means it is ignoring the information from the oxygen sensor. The duration of the pulse that is sent to the injectors will be determined by the functions which are used as an input and the tables. The block in the table that is used will depend on the inputs like the engine rpm that is received into the ECA. If the engine rpm goes over the scalar amount of 6,000 rpm, this value will be used by the ECA to back off on the amount of fuel sent to the injectors to reduce the speed

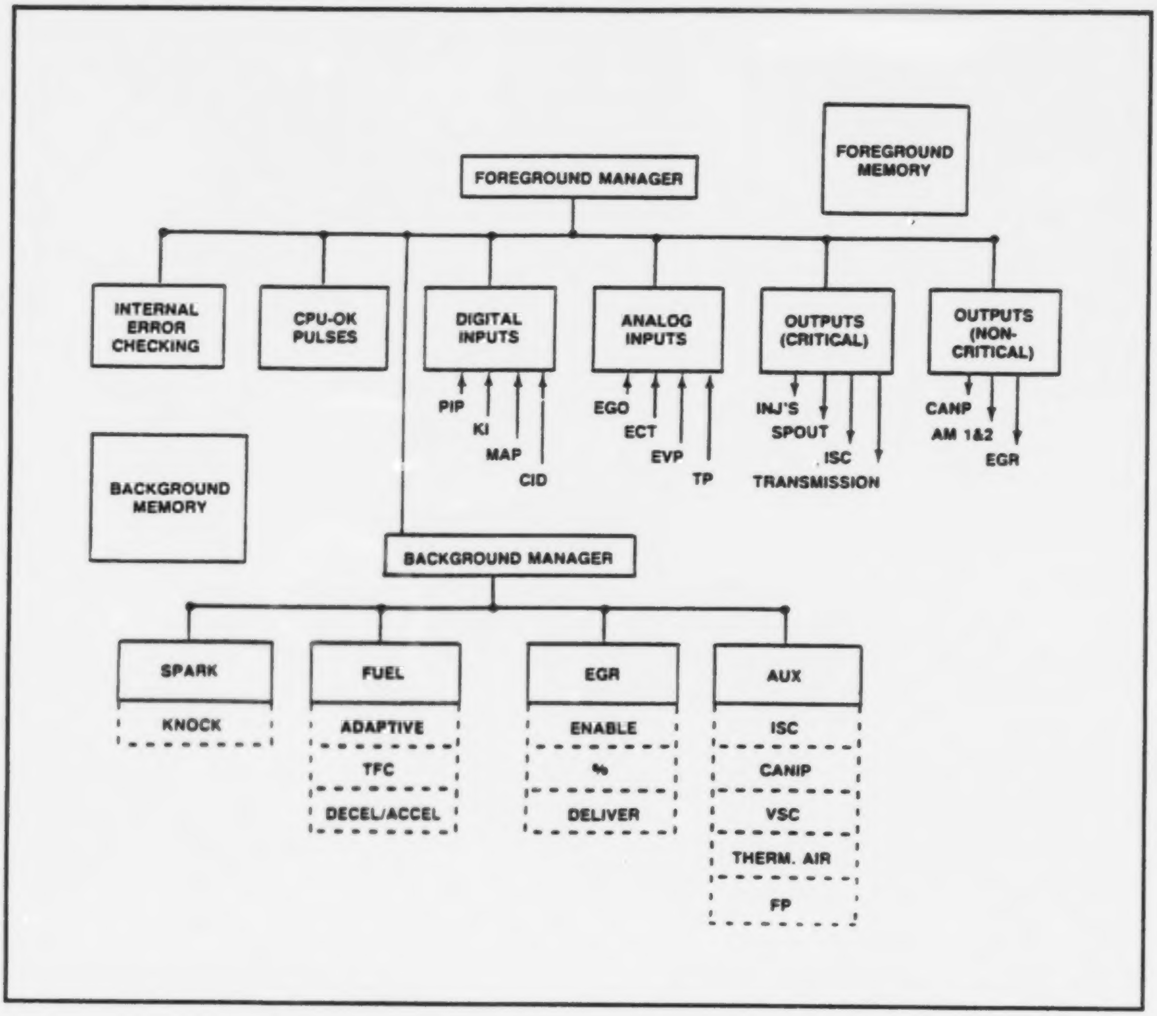

FOREGROUND MANAGER
FOREGROUND MEMORY
INTERNAL ERROR CHECKING
CPU-OK PULSES
DIGITAL INPUTS
ANALOG INPUTS
OUTPUTS (CRITICAL)
OUTPUTS (NON-CRITICAL)
PIP
KI
MAP
CID
EGO
ECT
EVP
TP
INJ'S
SPOUT
ISC
TRANSMISSION
CANP
AM 1&2
EGR
BACKGROUND MEMORY
BACKGROUND MANAGER
SPARK
KNOCK
FUEL
ADAPTIVE
TFC
DECEL/ACCEL
EGR
ENABLE
%
DELIVER
AUX
ISC
CANIP
VSC
THERM. AIR
FP

Fig. 9. Foreground and background managers. (Courtesy of Ford Motor Company)

of the engine and hold it under the maximum limit.

The data put into the tables and the functions used are put there by the engineers for that particular model of car with that engine and accessories. This information has been developed to provide the best possible engine performance, emissions, and drivability. This data and information that is stored in the tables and functions is not perfect for the car. The engine will wear, the injectors will start to become clogged, and performance will suffer. In the past, a car would have its spark plugs and points changed and the parts adjusted, or what is simply called a tune-up to correct for the normal wear of components. The ECA, however, has the ability to learn and adjust its output to compensate for the normal wear and change of the injectors and the other components in the system.

When the car is first started, the ECA runs open loop, which means there is no feedback from the oxygen sensor. Under these conditions, it will be operating from the data in the tables and the functions. As the oxygen sensor warms up to its operating condition, the ECA starts receiving data from it and changes to a closed loop condition. In the tables there is data that tells the ECA how wide the pulse to send to the injectors should be for certain engine speeds and throttle positions. When the system is receiving data from the oxygen sensor, these values are changed to correct for the actual conditions that are present.

For example, if the injectors have become clogged as a result of poor quality gasoline (fig. 10), the ECA will increase the pulse width to the injector to put more fuel into the engine. This corrects the balance of fuel and air going to the engine and maintain proper combustion with low emissions. These values remain in the tables and are used in the open loop condition the next time the car is started.

If the battery is removed for any reason, such as during service, the learned data in the tables is lost, and the system will go back to the original data put there by the engineers. It will generally take about an hour of running to regain enough of the lost or learned data before the drivability of the car starts to feel normal. All of the learned data may not be recovered until the car has gone through all situations; for example, there will be learned data that can only be obtained under full throttle, and other data that is obtained under hard braking.

A technician should try to avoid delivering a car back to its owner with all of the learned data lost. One way to avoid this is to put another battery on line while the orginal is removed so as to avoid a total power loss. For most cars, the orginal data put there by the

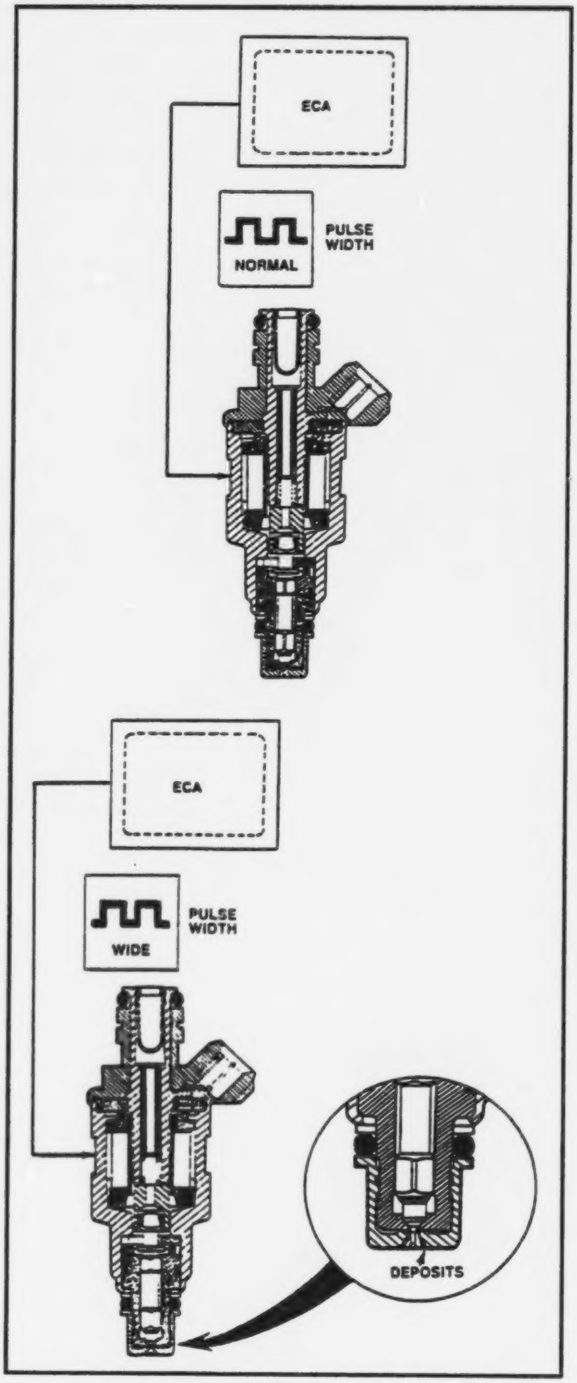


Fig. 10. Normal injector (TOP) and clogged injector (BOTTOM). (Courtesy of Ford Motor Company)

engineers is in ROM, which is not affected by a power loss. The learned data is in RAM, which will be gone with a power loss.

If an input sensor fails and is replaced, it would be a good idea to clear the memory of the learned data. The ECA will have adjusted for the weak input sensor. The ECA will be operating on data in the tables that compensates for the weak sensor, which will result in the engine running poorly. Clearing the learned data will increase the rate of learning for the new sensor and result in improved performance.

Diesel Engines

Most diesel engines used on automobiles at the present time use a mechanical system to control the fuel injection to the cylinders. The electronic controls on the fuel system in a diesel engine are used to control the glow plugs. The glow plugs (fig. 11) warm up the cylinders during the starting process.

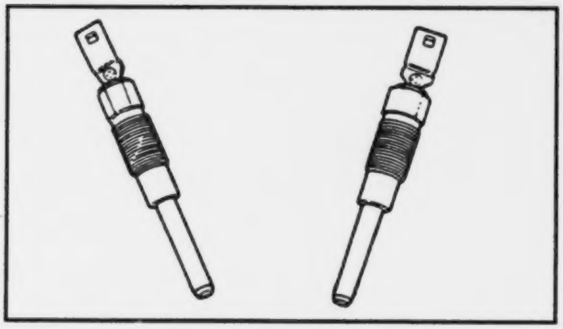
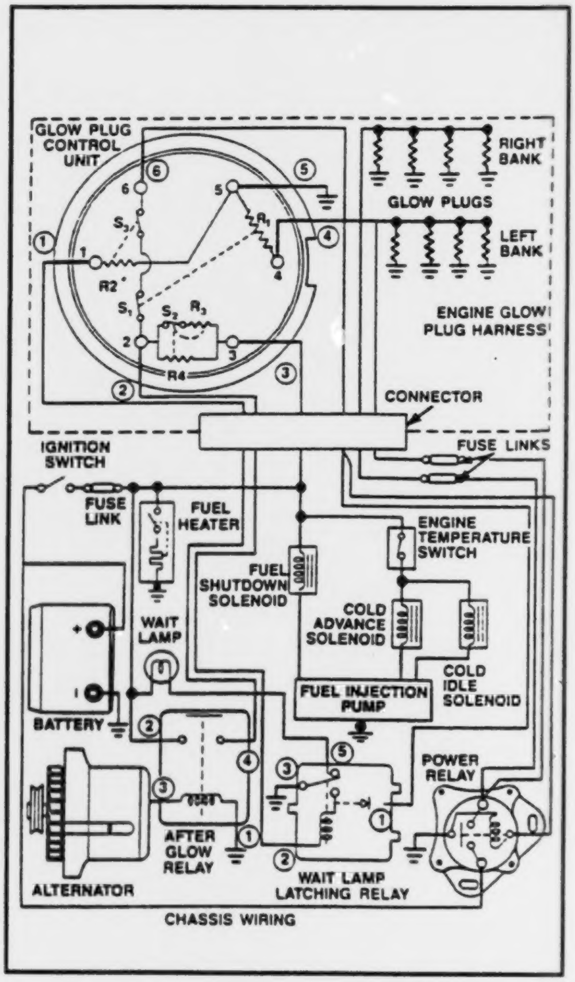


Fig. 11. Glow plugs. (Courtesy of Ford Motor Company)

To keep the glow plugs from burning out, the voltage to the plugs is cycled on and off. For most glow plugs, the plug should not have voltage applied for more than 15 seconds. A sensor which measures the temperature of the engine coolant will act as the input sensor to determine the length of time that the plugs receive voltage. The time will vary from a few seconds to about 10 seconds for most cars.



GLOW PLUG CONTROL UNIT
⑥
6
⑤
5
①
1
S3
R1
④
4
R2
S1
S2
R3
2
3
R4
③
②
RIGHT BANK
GLOW PLUGS
LEFT BANK
ENGINE GLOW PLUG HARNESS
CONNECTOR
IGNITION SWITCH
FUSE LINKS
FUSE LINK
FUEL HEATER
FUEL SHUTDOWN SOLENOID
ENGINE TEMPERATURE SWITCH
COLD ADVANCE SOLENOID
WAIT LAMP
+
BATTERY
FUEL INJECTION PUMP
COLD IDLE SOLENOID
POWER RELAY
②
④
③
⑤
③
①
①
②
ALTERNATOR
AFTER GLOW RELAY
WAIT LAMP LATCHING RELAY
CHASSIS WIRING

Fig. 12. Glow plug electrical system. (Courtesy of Ford Motor Company)

When the engine is started, the alternator will cause the power to the glow plugs to be interrupted. The control unit for the glow plugs has resistance-heated bimetallic strips (fig. 12). These strips are used to cycle the voltage to the glow plugs.

The bimetallic strip labeled S_2 is heated by the alternator and after 20 to 90 seconds will open, disconnecting all voltage to the glow plugs. The glow plug system is allowed to run for this extra time after the engine is started to reduce start-up smoking.

Exercise

1. When the ECA is operating "OPEN LOOP," which input sensor is ignored?
2. In a fuel-injected system, which output from the ECA is the most important output for controlling the air-fuel ratio?
3. What is the approximate pressure of the fuel in the lines going to the engine?
4. If the driver pushes the throttle to the floor, what information from the oxygen sensor is used by the ECA?
5. Explain why the car may have poor drivability or run rough after the owner has the battery changed.
6. A technician is having trouble starting a diesel car. The technician notices that the voltage going to the glow plugs is intermittent. The technician decides to connect battery voltage directly to the glow plugs in order to start the car. What components will have to be changed?
7. What sensor input is used on a glow plug system in a diesel car?

F-2 Engine Fuel Delivery Systems

Workbook

Essential Elements: (gg)(1, 2, 4, and 5)

Figure 1 shows the electrical schematic for a typical electronically controlled fuel-injected engine. The lines going to small circles with numbers show the pin numbers for the connector to the ECA or computer. The components across the top are the input sensors for the system.

1. Take a separate piece of paper and redraw the schematic for the circuit to the fuel pump. Note that there is continuity through the plug located at the bottom center of the drawing.

2. We can assume that there is no resistance in the plugs or the inertia switch in the fuel pump circuit, and that the fuel pump draws 3 amp. Assume that the battery voltage is 12.4 volts, and calculate the voltage measured to ground at the input to the fuel pump, located at the number 787.

3. Locate and record the pin numbers on the harness connector that go to ground.

4. Look at the wire color information at the bottom right of figure 1. Use a separate piece of paper to write the colors of the wires coming from the following pin numbers on the harness connector: 23, 4, 18, 29, 9, 12.

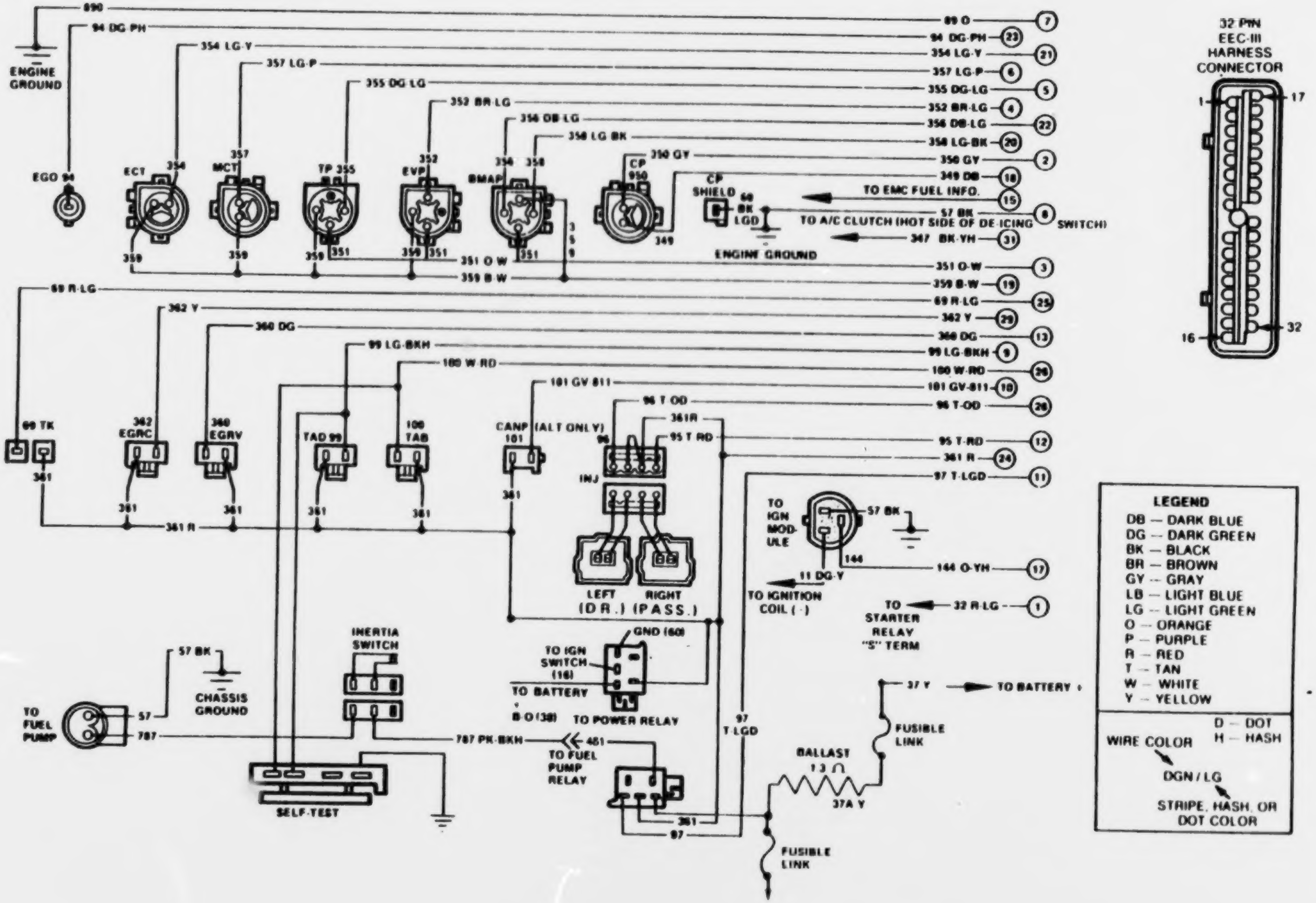

ENGINE GROUND
890
89 O
94 DG-PH
354 LG-Y
357 LG-P
355 DG-LG
352 BR-LG
356 DB-LG
358 LG-BK
350 GY
349 DB
TO EMC FUEL INFO.
57 BK
TO A/C CLUTCH (HOT SIDE OF DE-ICING SWITCH)
347 BK-YH
351 O-W
359 B-W
69 R-LG
362 Y
360 DG
99 LG-BKH
100 W-RD
101 GY-811
96 T-OD
95 T-RD
361 R
97 T-LGD
144 O-YH
32 R-LG
EGO 94
ECT
MCT
TP 355
EVP
BMAP
CP 950
CP SHIELD
LGD
69 TK
362 EGRC
360 EGRV
TAD 99
100 TAB
CANP (ALT ONLY) 101
INJ
LEFT (D.R.)
RIGHT (PASS.)
TO IGN MODULE
11 DG-Y
TO IGNITION COIL (-)
TO STARTER RELAY "S" TERM
TO IGN SWITCH (16)
GND (60)
TO BATTERY
B-O (38)
TO POWER RELAY
INERTIA SWITCH
57 BK
CHASSIS GROUND
TO FUEL PUMP
787
787 PK-BKH
481
TO FUEL PUMP RELAY
SELF-TEST
37 Y
TO BATTERY +
FUSIBLE LINK
BALLAST 1.3 Ω
37A Y
FUSIBLE LINK
32 PIN EEC-III HARNESS CONNECTOR
1
17
16
32
LEGEND
DB — DARK BLUE
DG — DARK GREEN
BK — BLACK
BR — BROWN
GY — GRAY
LB — LIGHT BLUE
LG — LIGHT GREEN
O — ORANGE
P — PURPLE
R — RED
T — TAN
W — WHITE
Y — YELLOW
D — DOT
H — HASH
WIRE COLOR
DGN / LG
STRIPE, HASH, OR DOT COLOR

Fig. 1. A typical Ford 5.0L EEC-III/CFI system electrical schematic. (Courtesy of Ford Motor Company)

F-3

Ignition Systems

Essential Elements: (gg)(1, 2, 4, and 5)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals and operation of:

- *automotive sensors*
- *the fuel delivery system*
- *the electronic ignition system*
- *the emission control system*
- *the diesel fuel delivery and control system*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how a sensor tells the direct ignition system which companion pair of spark plugs to fire*
- *explain how the Hall effect switch is used as a sensor to detect the position of the crankshaft and cam*

Ignition Systems

Automotive manufacturers have been rapidly developing new and better methods for controlling the timing of the spark to the spark plugs. The original system involving points was a mechanical switch that operated off a cam in the distributor. This cam and mechanical switch was replaced with an electronic sensor for the cam and a transistor for the mechanical switch (fig. 1).

One problem with this system is that it is still switching high voltage in the distributor cap and rotor. This mechanical switching results in less spark timing accuracy and more wear on the electrical surfaces.

The direct ignition system is the next step up from the electronic ignition system. This system has a sensor located on the crankshaft which feeds positional data to the engine control module or computer (fig. 2). The engine control module (ECM) sends current pulses to the coils which provide the high voltage to the spark plugs.

The high voltage from the coils is never switched by a distributor, resulting in improvements over the cap and rotor of the electronic ignition system. The direct ignition system also has computer control of the spark timing.

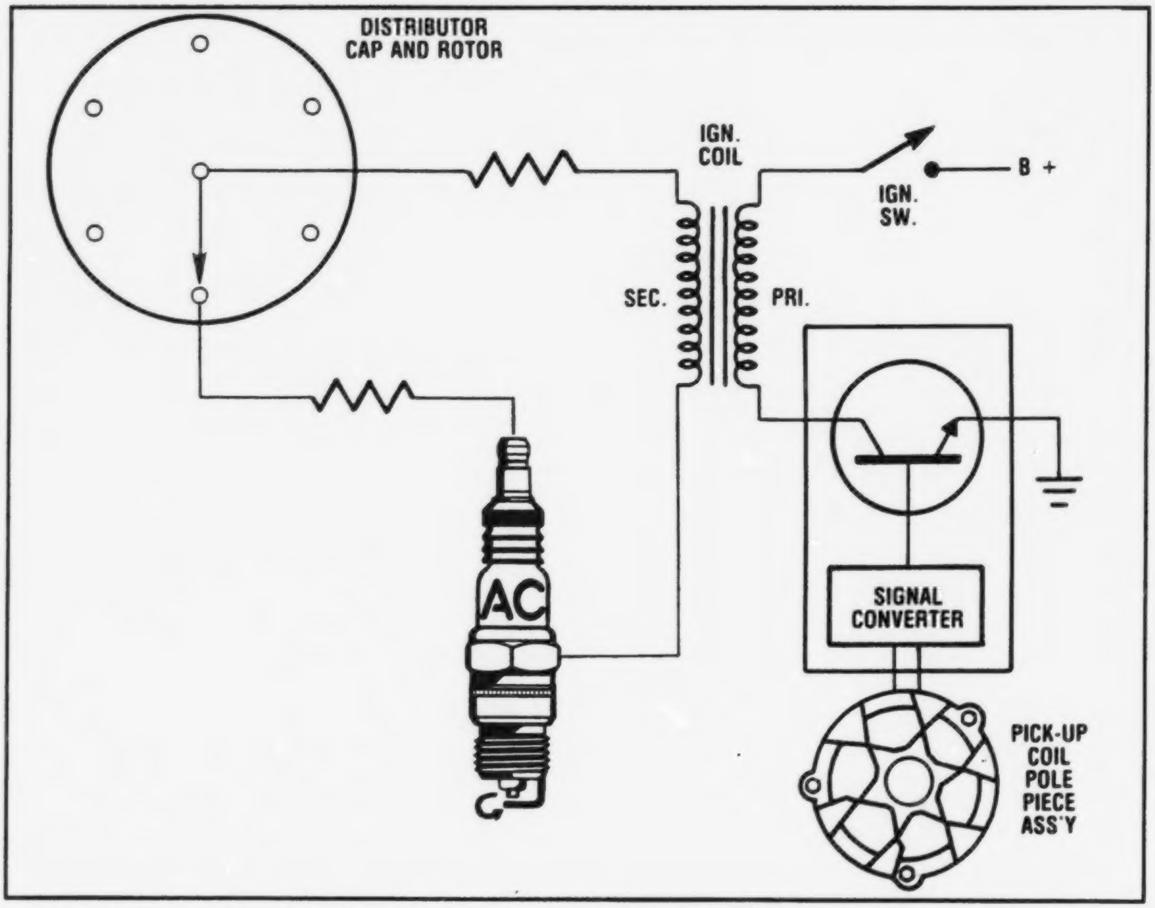

DISTRIBUTOR
CAP AND ROTOR
IGN.
COIL
IGN.
SW.
B +
SEC.
PRI.
AC
SIGNAL
CONVERTER
PICK-UP
COIL
POLE
PIECE
ASS'Y

Fig. 1. Conventional electronic ignition system. (Courtesy of General Motors Corporation)

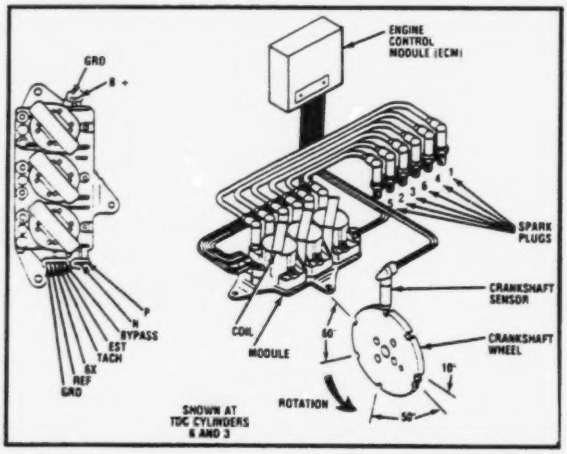

ENGINE
CONTROL
MODULE (ECM)
GRD
B +
1
4
6
3
2
5
SPARK
PLUGS
CRANKSHAFT
SENSOR
CRANKSHAFT
WHEEL
P
N
BYPASS
EST
TACH
6X
REF
GRD
COIL
MODULE
60°
10°
50°
ROTATION
SHOWN AT
TDC CYLINDERS
6 AND 3

Fig. 2. Direct ignition system. (Courtesy of General Motors Corporation)

The electronic ignition system always sent a negative high voltage to the center electrode of the spark plug. A negative high voltage on the center electrode is a little more efficient than feeding the negative voltage to the body of the plug. The direct ignition system sends both positive and negative high voltage to the spark plugs. Both the top and bottom of the secondary coil are connected to spark plugs. This results in one coil for every two plugs (fig. 3).

Each time the coil primary is energized, high voltage on the secondary will be sent to two spark plugs at the same time. A six-cylinder engine will have three high-voltage coils to fire the six spark plugs. The two plugs on each coil are located on the companion cylinders that both reach top dead center at the same time. One of the companion cylinders will be on the compression stroke, called the *event* cylinder, and the other companion cylinder will be on the exhaust stroke, called the *waste* cylinder. When the coil is energized, high voltage is sent to both the plug in the event cylinder and the plug in the waste cylinder. This arrangement, with two plugs, requires a little more voltage to effectively fire both plugs.

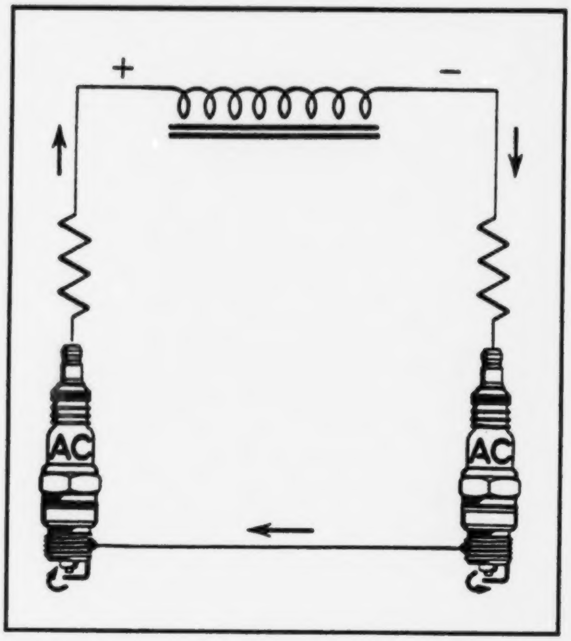


Fig. 3. D.I.S./C_3I current flow. (Courtesy of General Motors Corporation)

Remember that the crankshaft rotates once for any cylinder to reach its exhaust stroke, and then the crankshaft rotates again for that cylinder to reach its compression stroke. Since both the compression and exhaust cylinders are fired at the same time, it is not necessary for the computer module to be able to identify which cylinder is on its compression stroke.

Each of the coils in this system will have its primary current controlled by a transistor in the computer module (fig. 4). When the control circuit feeds current to the transistor base circuit, the transistor turns on. The more current that is fed to the base of the transistor, the more current allowed to go to ground through the primary coil.

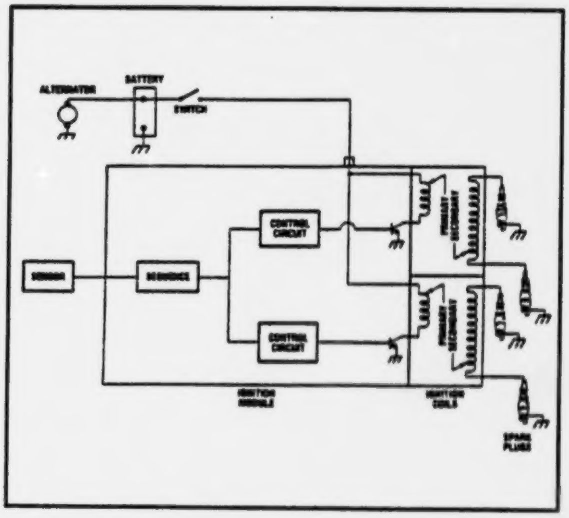


Fig. 4. Direct ignition system schematic. (Courtesy of General Motors Corporation)

Notice in figure 4 that the spark plugs are in series with the secondary of the coil. If one plug were to fail open, the other companion plug would also not fire. The circuitry inside the computer module will control the amount of primary current and the duration or dwell of that current. The primary winding of the coil is approximately 1 ohm. You can use Ohm's law to determine that 13 volts divided by 1 ohm will result in 13 amp of current. To avoid burning out the primary windings, the current must be limited to less than 10 amp. The control circuitry in the module will limit the current and control the dwell time.

For some systems, the module will monitor the current in the coil and adjust the duration or dwell to operate the coil near saturation (fig. 5). The drawing shows a graph of the first event in which the current is maintained at 8.5 to 10 amp for a period that was more than necessary to take the coil into saturation. The system corrected itself for the second time by shortening the length of time that current was allowed through the coil. We would call this closed loop *dwell control*.

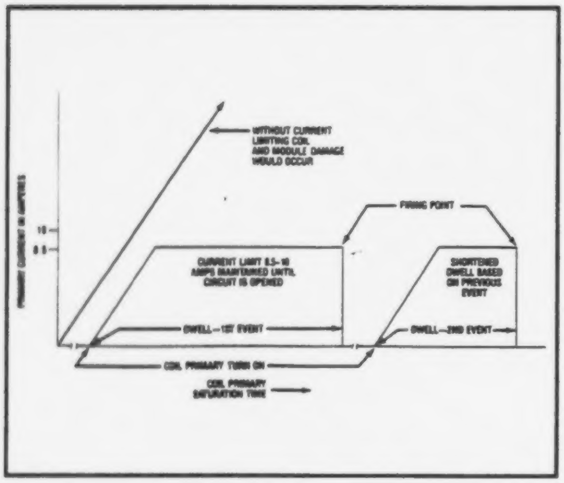


Fig. 5. Current limiting and dwell control schematic. (Courtesy of General Motors Corporation)

Ignition Triggering Sensors

The computer module obtains its timing information from a sensor on the crankshaft (fig. 6). The magnetic type sensor can be either a Hall effect sensor or a magnetic sensor and reluctor. The magnetic sensor and reluctor uses a coil around a permanent magnet to form the sensor, which is mounted about 0.05 inch from the crankshaft.

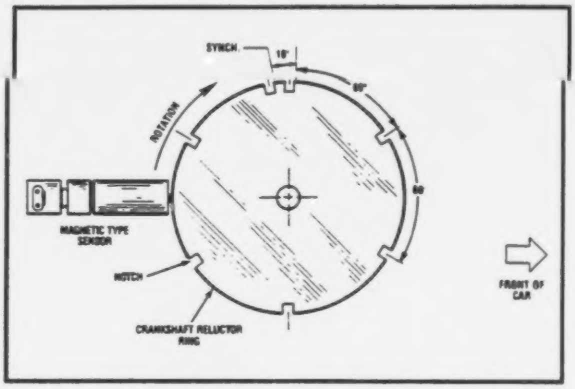

SYNCH.
10°
60°
60
ROTATION
MAGNETIC TYPE SENSOR
NOTCH
CRANKSHAFT RELUCTOR RING
FRONT OF CAR

Fig. 6. Magnetic sensor and reluctor type triggering system. (Courtesy of General Motors Corporation)

The magnetic field in the sensor is changed by the reluctor, which is the machined outer part of the gear (fig. 6). The notches in the reluctor change the magnetic field when they pass the sensor. Any change in a magnetic field will induce a voltage in the coil surrounding the magnet (fig. 7).

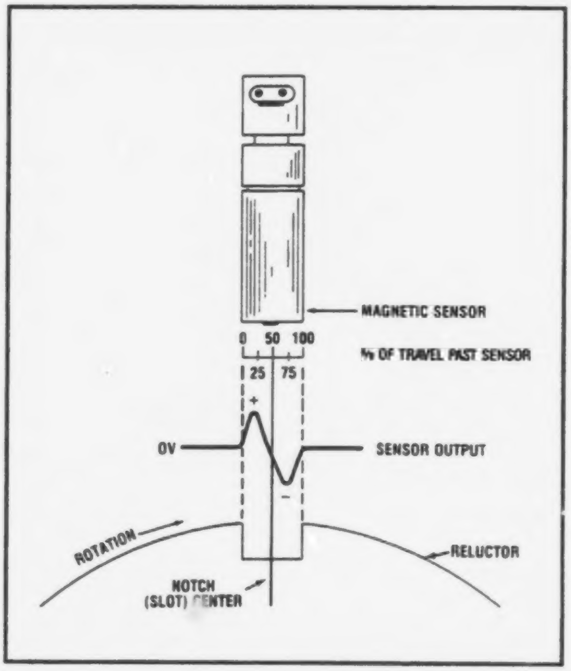

MAGNETIC SENSOR
0
50
100
25
75
% OF TRAVEL PAST SENSOR
+
OV
SENSOR OUTPUT
−
ROTATION
RELUCTOR
NOTCH (SLOT) CENTER

Fig. 7. Notch effect on output signal. (Courtesy of General Motors Corporation)

As the speed of the wheel increases, the voltage output will increase, although the shape of the signal will remain the same. Table 1 shows the minimum voltage expected under cranking conditions. With the engine running at high rpm, the voltage can be over 100 volts.

Engine	Coil Resistance at 70° F	Minimum Output Cranking
2.0L, 2.8L, 3.1L	900–1200Ω	100 mVAC
2.3L (Quad 4)	500–900 Ω	200 mVAC
2.5L	800–900 Ω	N/A

Table 1. Magnetic Crank /Sensor Specifications. (Courtesy of General Motors Corporation)

Since the output from the sensor fluctuates above and below 0 volts, you should use the ac function of your DVOM to read the voltage. The sensor is probably working if you get an ac voltage that is above the levels listed in table 1 when the engine is cranked.

The reluctors around the crankshaft on both the four- and six-cylinder engines used by GM have seven notches (fig. 8). Remember that for a four-cylinder engine, only two pulses to the coils from the computer module are necessary. The crankshaft tells the computer module to fire cylinders 2 and 3 as the companion pair when notch number 2 passes the sensor. The module will know that this is notch number 2 after it has passed the double notch and notch number 1. After notch number 2, it passes notch number 3 and 4 and then fires cylinder pair 1 and 4 on notch number 5.

Figure 9 shows the same sensor and reluctor as in figure 8, but for a six-cylinder engine instead of the four-cylinder in figure 8. Notice that the cylinder pairs are fired on notches 2, 4, and 6 this time. The double notch on notch 6 tells the module which pair is to be fired first. The notch in front of the timing notch is used to send signals to the module concerning engine rpm, fuel injection, and spark timing duration.

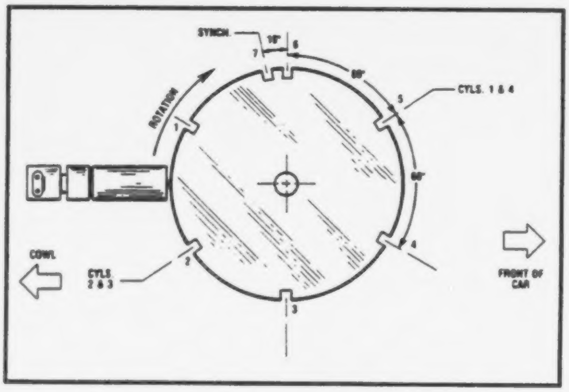


Fig. 8. Seventh notch synchronizes coil firing sequence with crankshaft position. (Courtesy of General Motors Corporation)

Hall Effect Sensors

Hall effect sensors are used in a variety of packages (fig. 10). They all use the same principle of detecting the presence of a magnetic field.

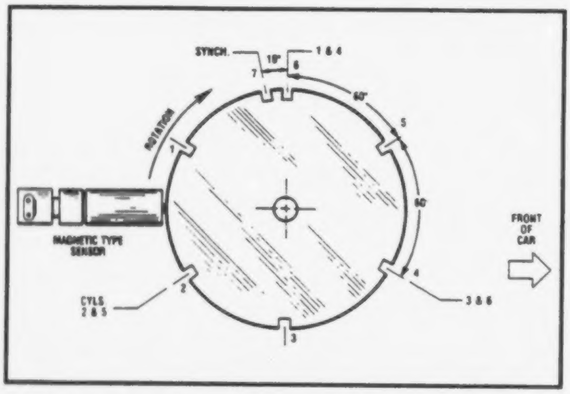


Fig. 9. On six-cylinder engines, the module skips number 1 notch and fires cylinders 2 and 5 from notch number 2. (Courtesy of General Motors Corporation)

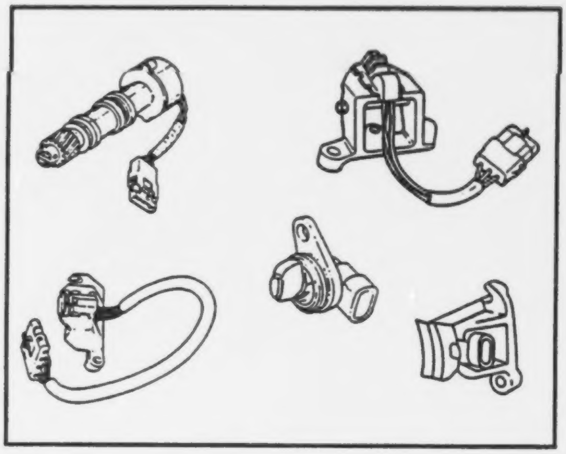


Fig. 10. Hall effect sensors. (Courtesy of General Motors Corporation)

This Hall effect was discovered by Dr. Hall when he found that a voltage can be induced in a conductor when it is in the presence of a magnetic field. The magnetic lines of force have to be perpendicular to a separate current flowing in the conductor (fig. 11). When these conditions are met, the voltage shown as VO+ and VO- will be present.

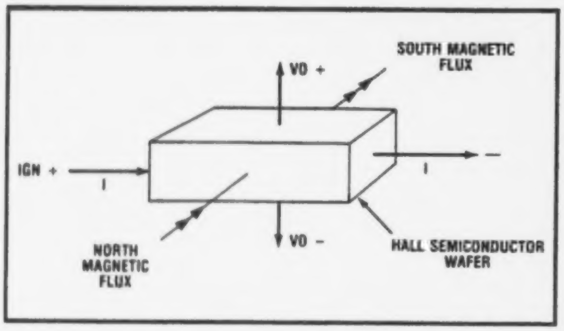

SOUTH MAGNETIC FLUX
VO +
IGN +
I
I
NORTH MAGNETIC FLUX
VO −
HALL SEMICONDUCTOR WAFER

Fig. 11. Hall effect. (Courtesy of General Motors Corporation)

The conductor commonly used for Hall effect devices is silicon semiconductor material. This is the same material used to make transistors and diodes. Notice, that for the Hall effect to work, it is necessary to properly orientate the magnetic lines of force with the receiving sensor and an external current has to be supplied.

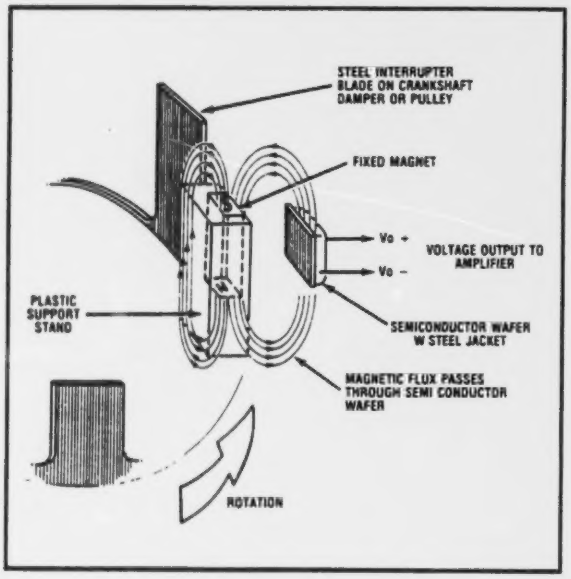

STEEL INTERRUPTER BLADE ON CRANKSHAFT DAMPER OR PULLEY
FIXED MAGNET
Vo +
Vo −
VOLTAGE OUTPUT TO AMPLIFIER
PLASTIC SUPPORT STAND
SEMICONDUCTOR WAFER W STEEL JACKET
MAGNETIC FLUX PASSES THROUGH SEMI CONDUCTOR WAFER
ROTATION

Fig. 12. Hall switch ON. (Courtesy of General Motors Corporation)

A typical application of a Hall effect device used as a switch is shown in figure 12. This device is used as the sensor on the crankshaft for the ignition timing. A magnet and the Hall effect sensor are mounted close together so that the magnetic lines of force result in a Hall voltage coming from the sensor. The metal vanes mounted on the crankshaft will pass between the magnet and the Hall effect sensor as the crankshaft turns.

Figure 13 shows how the metal vane or interrupter on the crankshaft conducts the magnetic lines of force. The conduction of the magnetic lines of force will result in the lines of force not reaching the Hall effect sensor when the interrupter is between the magnet and the sensor. With the interrupter between the magnet and sensor, there is no Hall effect voltage coming from the sensor.

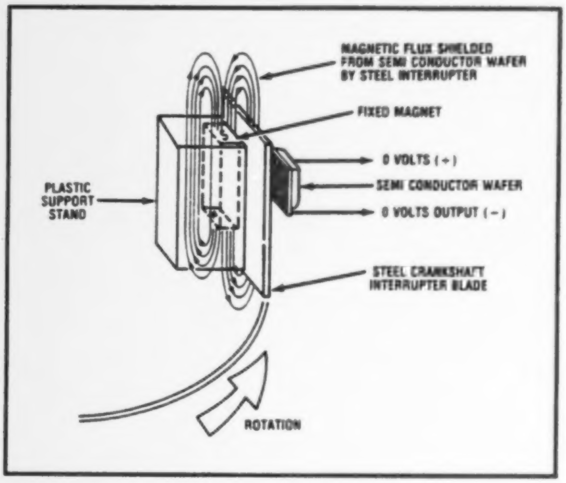

MAGNETIC FLUX SHIELDED FROM SEMI CONDUCTOR WAFER BY STEEL INTERRUPTER
FIXED MAGNET
0 VOLTS (+)
PLASTIC SUPPORT STAND
SEMI CONDUCTOR WAFER
0 VOLTS OUTPUT (−)
STEEL CRANKSHAFT INTERRUPTER BLADE
ROTATION

Fig. 13. Hall switch OFF. (Courtesy of General Motors Corporation)

The Hall voltage coming from the sensor will appear as pulses, of approximately 0.5 volt, when the crankshaft is rotating. These pulses are amplified and used for the timing of the ignition pulses and for fuel injection timing.

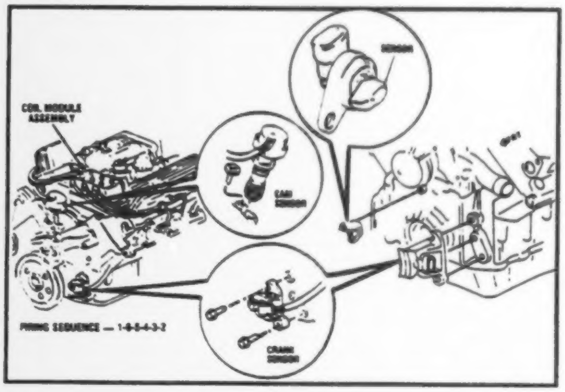

SENSOR
COIL MODULE ASSEMBLY
CAM SENSOR
FIRING SEQUENCE — 1-6-5-4-3-2
CRANK SENSOR

Fig. 14. Hall effect crank and cam sensors. (Courtesy of General Motors Corporation)

The Hall effect sensors are used in different locations on the engine to sense the position of different parts of the engine. Figure 14 shows some of the sensor locations for the GM 3.8L SFI turbo engine and nonturbo engine.

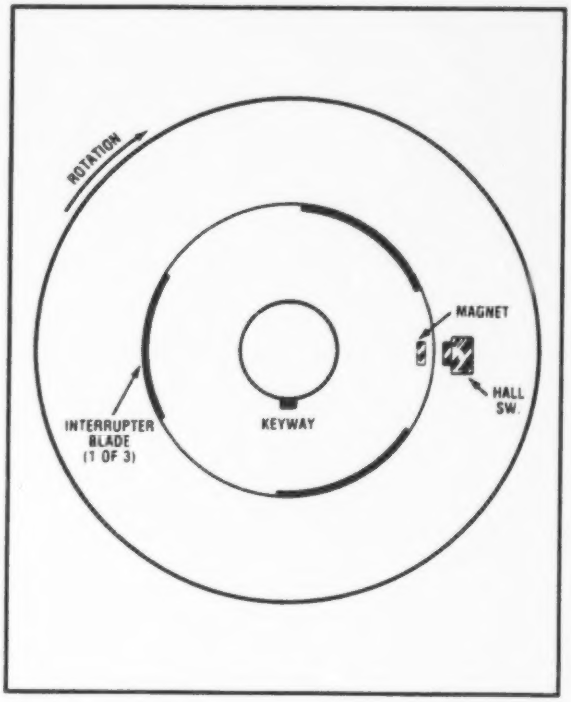

ROTATION
MAGNET
HALL SW.
KEYWAY
INTERRUPTER BLADE (1 OF 3)

Fig. 15. Crankshaft damper–viewed from front. (Courtesy of General Motors Corporation)

The GM 3.8L turbo engine uses three equally spaced interrupters on the crankshaft (fig. 15). The voltage pulses coming from this setup are equally spaced 0.5-volt pulses. Since all three pulses are equally spaced and timed, there is no way that this sensor can send information telling the computer module which companion pair of cylinders should receive which ignition pulse.

The correct sequence for the GM 3.8L turbo engine is determined by adding an additional Hall effect sensor on the cam. The cam sprocket rotates at half-speed and will send a pulse that will be synchronized with one of the crank pulses (fig. 16). This will mark that pulse for the computer module and allow the computer to send the ignition pulses in the proper sequence.

Exercise

1. For the conventional electronic ignition system, how many high voltage pulses per minute will each spark plug receive if the engine is running at 1,000 rpm? How many for the direct ignition system?

2. What is the minimum ac voltage output from a magnetic sensor on the crankshaft under cranking conditions for a 2.8L engine?

3. A technician was troubleshooting a problem with the ignition system. The technician found that the cylinder pair 2 and 5 did not fire. To check the coil, the technician connected battery voltage to the primary of the coil with no results. Then the technician noticed that one of the spark plugs had broken. When the plug was replaced, the companion pair still did not fire. What is the most probable reason for the companion pair not firing now?

4. What two inputs have to be present before a Hall effect device will output voltage?

5. What material is used to make Hall effect devices?

6. How does the GM 3.8L turbo engine determine the correct sequence for firing the companion pair spark plugs?

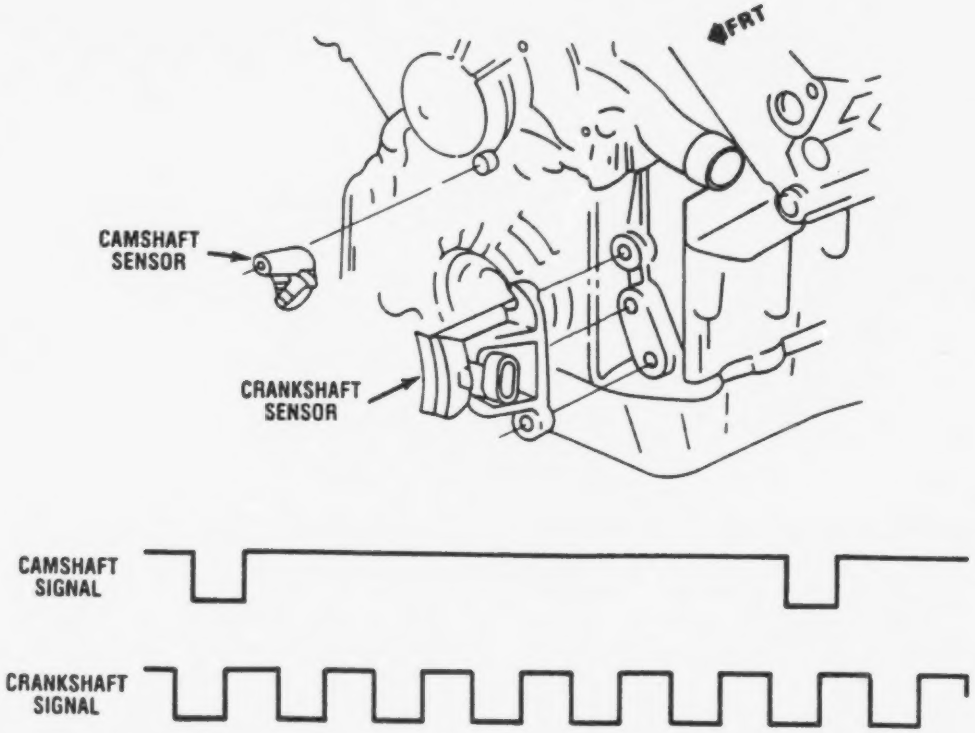


Fig. 16. Camshaft and crankshaft sensor locations. (Courtesy of General Motors Corporation)

F-3 Ignition Systems

Workbook

Essential Elements: (gg)(1, 2, 4, and 5)

Procedure

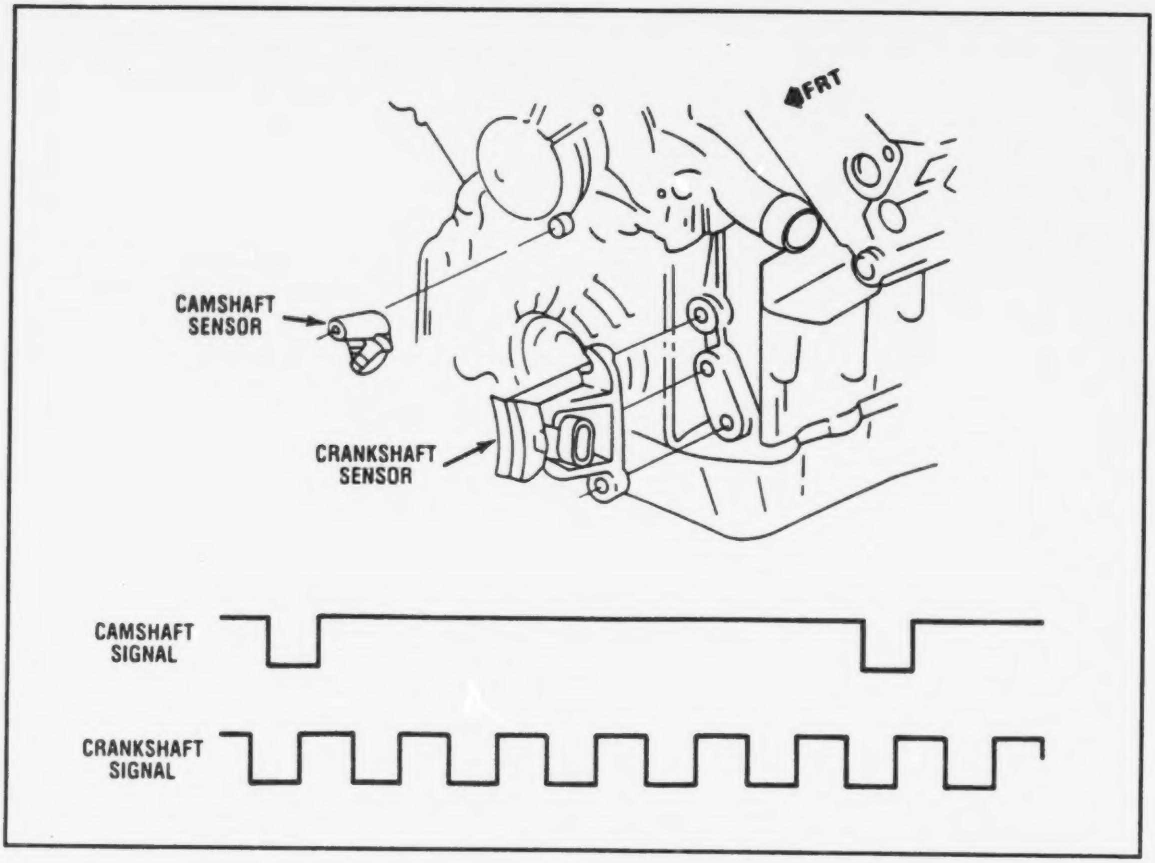

FRT
CAMSHAFT SENSOR
CRANKSHAFT SENSOR
CAMSHAFT SIGNAL
CRANKSHAFT SIGNAL

Fig. 1. Camshaft and crankshaft reference signals. (Courtesy of Ford Motor Company)

Figure 1 shows a schematic of the ignition computer module connections. Notice that the direct ignition system module has three plugs shown above and on the right side of the module. The two-pin plug is at the top of the module shown connected to engine ground and battery voltage through the ECM fuse and IGN or ignition switch assembly. The crank sensor is the type that uses a magnet inside a coil of wire. The signal output from this sensor will look like the drawing in figure 7 in the assignment, which you studied earlier.

1. Refer to figure 7 in the assignment, and draw the signal that you would expect to see coming from the crank sensor in figure 1. Draw the signal for one complete revolution from the crankshaft.
2. Redraw the inside of the direct ignition system module using transistors instead of the switches to control the input to the primary of the coils. The transistors should have their emitters connected to ground, the collector connected to the primary of the coil, and the base will be the input from the internal electronics in the module.
3. Draw the crankshaft as shown in figure 1, and show on the drawing which coil will be fired at which notch on the crankshaft. Note that there are only three coils since the coils fire the two companion cylinders for this six-cylinder engine.

F-4

Emission Control Systems

Essential Elements: (gg)(1, 2, 4, and 5)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals and operation of:

- *automotive sensors*
- *the fuel delivery system*
- *the electronic ignition system*
- *the emission control system*
- *the diesel fuel delivery and control system*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how harmful emissions are controlled*
- *explain the importance of the input sensors in controlling harmful emissions*

Combustion Process

The chemical compounds that make up today's gasoline are hydrocarbons. A hydrocarbon is a chemical that is composed of the elements hydrogen and carbon chemically bonded together. In addition to the usual hydrocarbons, there are the impurities and chemicals added by the refiner.

When the gasoline is burned in the combustion chamber of a typical automobile, the hydrogen and carbon combine with the oxygen from the air that is admitted and form water and carbon dioxide. If the burning process were perfect, the water and carbon dioxide would be the only products of the combustion.

The impurities, additives, and incomplete burning of the gasoline result in substances other than simply water and carbon dioxide being emitted from the combustion process. These other exhaust emissions are the substances that must not be released into the atmosphere.

Most of the harmful emissions consist of carbon monoxide from a lean engine, unburned hydrocarbons from a rich engine, oxides of nitrogen produced by the chemical union of oxygen and nitrogen, and oxides of sulfur and other compounds from the impurities in the gasoline. Many of these harmful emissions are reduced by the computer-controlled fuel injection system and computer control of the ignition system.

As the standards have become tighter for emission controls, the need for electronic controls and a total engine design to control emissions has become necessary. The reason for extensive electronic control of new automobiles is primarily to reduce harmful emissions.

Emission Control Systems

There are five general systems for control of harmful emissions. The *positive crankcase ventilation (PCV)* system is the oldest emission control system. This system involves routing the harmful gases that blow by the pistons in the crankcase (fig. 1) back into the fresh air intake into the engine. This system first showed up in the early 1960s.

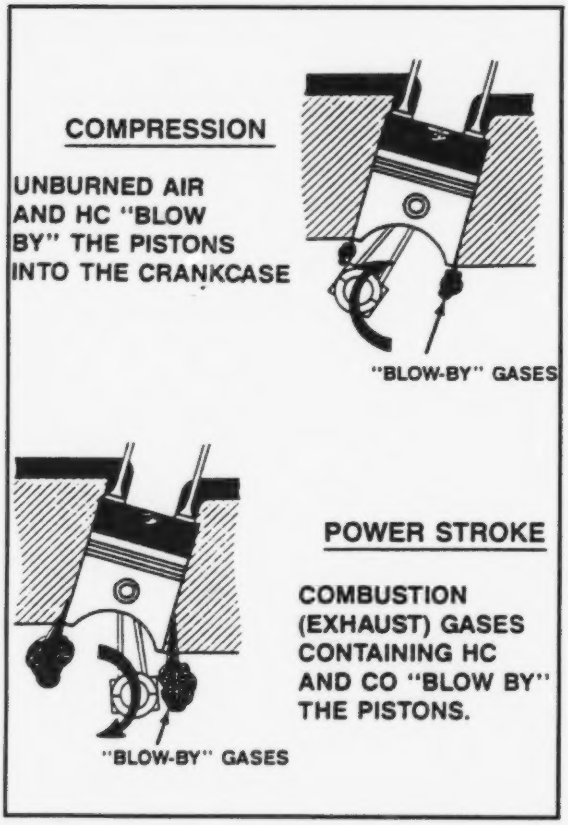

COMPRESSION
UNBURNED AIR AND HC "BLOW BY" THE PISTONS INTO THE CRANKCASE
"BLOW-BY" GASES
POWER STROKE
COMBUSTION (EXHAUST) GASES CONTAINING HC AND CO "BLOW BY" THE PISTONS.
"BLOW-BY" GASES

Fig. 1. The crankcase is vented to eliminate "blow-by" gases. (Courtesy of Ford Motor Company)

The *secondary air (Thermactor)* system first appeared around the mid-1960s. This system puts fresh air into the exhaust to reduce unburned hydrocarbons and carbon monoxide. In the '70s, catalytic converters were added to this system. Figure 2 shows a typical Thermactor system with the air pump feeding air to the catalytic converters.

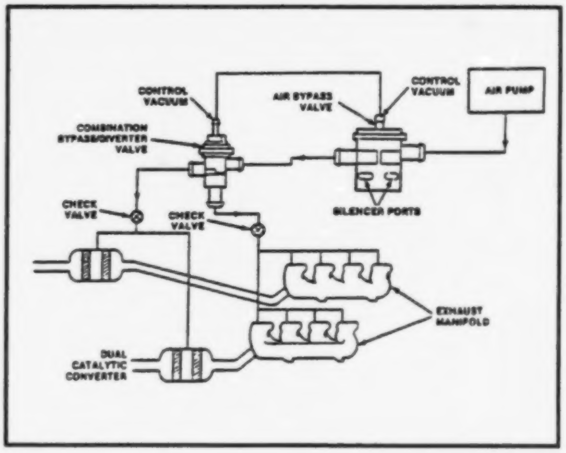

CONTROL VACUUM
AIR BYPASS VALVE
CONTROL VACUUM
AIR PUMP
COMBINATION BYPASS/DIVERTER VALVE
CHECK VALVE
CHECK VALVE
SILENCER PORTS
EXHAUST MANIFOLD
DUAL CATALYTIC CONVERTER

Fig. 2. Typical managed Thermactor air system. (Courtesy of Ford Motor Company)

The *IMCO (improved combusion)* system also first appeared in the 1960s. This system involved engine modifications designed to improve the combustion process and reduce unburned hydrocarbons and carbon monoxide in the exhaust. It included a heated primary air, carburetor design changes, and spark timing changes. The modern engines with their numerous controls grew out of these early developments.

In the 1970s, the fuel tank and the carburetor became a sealed system to control the evaporation of gasoline into the atmosphere. This system is called the *evaporative control* system. Today, there are extensive controls and systems to reduce and eliminate raw gasoline from evaporating into the air (fig. 3).

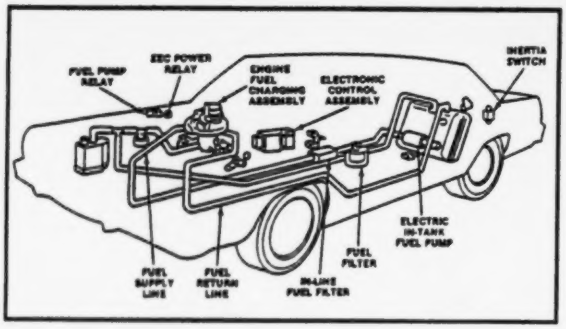

FUEL PUMP RELAY
EEC POWER RELAY
ENGINE FUEL CHARGING ASSEMBLY
ELECTRONIC CONTROL ASSEMBLY
INERTIA SWITCH
ELECTRIC IN-TANK FUEL PUMP
FUEL FILTER
IN-LINE FUEL FILTER
FUEL RETURN LINE
FUEL SUPPLY LINE

Fig. 3. Typical CFI fuel system. (Courtesy of Ford Motor Company)

The *exhaust gas recirculating (EGR)* system is used to reduce the amount of nitrogen oxides in the exhaust gases. This is done by adding some exhaust gas to the air-fuel mixture using the EGR valve (fig. 4). The exhaust gases do not burn, which results in a lower combustion chamber temperature so less nitrogen oxide is formed.

Electronic Engine Controls for Emissions Control

The electronic engine controls used by Ford for emission control work by controlling the air-fuel mixture and emissions systems. It uses a large number of sensors (fig. 5).

Figure 5 shows the location of the sensors and output devices for the Ford turbo engine. Figure 6 is the schematic showing the electrical connections for these components.

This schematic shows the computer module connections on the left. Notice that the EGR solenoid valve and the injectors are controlled by this computer module. The air conditioning is also controlled by this computer module.

In the closed loop mode of operation, the computer module will adjust the injector pulse based on feedback from the oxygen sensor. The computer module also controls the EGR valve, which allows exhaust gas to enter the intake air. With the exhaust gas mixed in with the fresh air, there is a reduction in the amount of oxygen present in the air. The computer module adjusts the pulse width sent to the in-

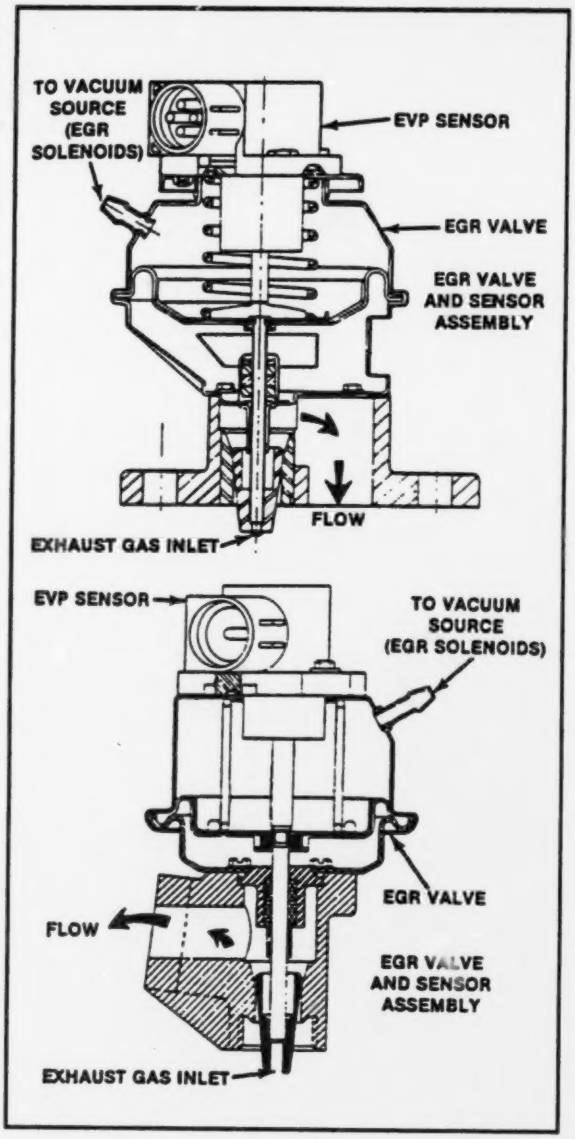

TO VACUUM SOURCE (EGR SOLENOIDS)
EVP SENSOR
EGR VALVE
EGR VALVE AND SENSOR ASSEMBLY
FLOW
EXHAUST GAS INLET
EVP SENSOR
TO VACUUM SOURCE (EGR SOLENOIDS)
EGR VALVE
FLOW
EGR VALVE AND SENSOR ASSEMBLY
EXHAUST GAS INLET

Fig. 4. Typical EGR valves–base and side entry. (Courtesy of Ford Motor Company)

jectors to decrease the fuel injected for the reduced amount of oxygen. This adjustment is fine-tuned by the feedback from the oxygen sensor. The oxygen sensor is a major part of the feedback or closed loop system. Without the information from the oxygen sensor, there would be no data to feed back to the computer for closed loop operation.

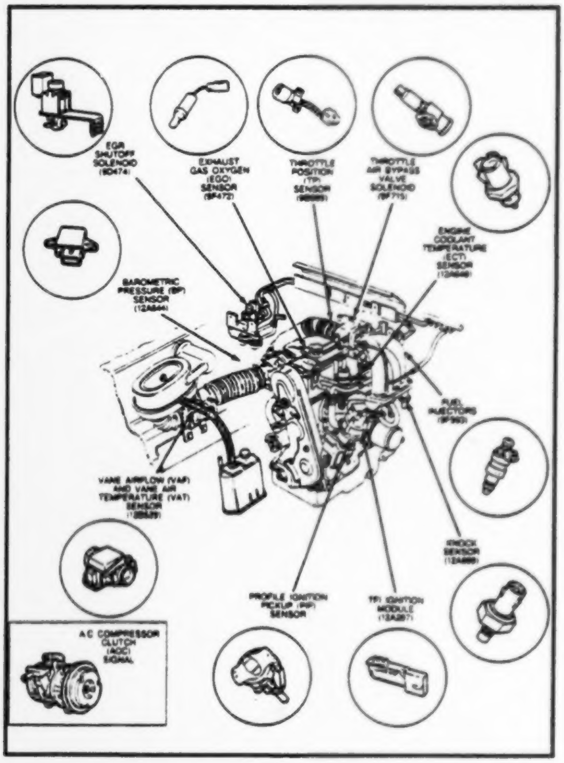

EGR SHUTOFF SOLENOID (9D474)
EXHAUST GAS OXYGEN (EGO) SENSOR (9F472)
THROTTLE POSITION (TP) SENSOR
THROTTLE AIR BYPASS VALVE SOLENOID (9F715)
ENGINE COOLANT TEMPERATURE (ECT) SENSOR
BAROMETRIC PRESSURE (BP) SENSOR (12A644)
FUEL INJECTORS
VANE AIRFLOW (VAF) AND VANE AIR TEMPERATURE (VAT) SENSOR
KNOCK SENSOR
PROFILE IGNITION PICKUP (PIP) SENSOR
TFI IGNITION MODULE (12A297)
AC COMPRESSOR CLUTCH (ACC) SIGNAL

Fig. 5. 2.3L EEC-IV turbo component location. (Courtesy of Ford Motor Company)

Sensor Inputs

The throttle position sensor uses a potentiometer to sense the position of the throttle. There are two types of sensors. One uses a wiper that rotates around on the resistance (fig. 7), and the other moves the wiper up and down in a straight line (fig. 8). The potentiometer with the straight movement is often called a *linear* sensor. This should not be confused with the electronic term for linear, which describes the relationship between the mechanical movement of the pot and the change in resistance.

On some of these throttle position sensors, it is possible to adjust the output voltage. The sensor in figure 8 has an adjusting screw that can move the wiper, changing the reference voltage for that point.

The barometric and manifold absolute pressure sensors are very similar. The BAP or barometric sensor (fig. 9) is used to measure the outside air pressure, which will change when the automobile climbs to a higher altitude. The MAP or manifold pressure sensor (fig. 10) is used to measure the vacuum in the manifold.

Both the MAP and the BAP generate an ac signal. The frequency of the signal indicates the pressure reading. This signal is used to modify the air-fuel ratio, spark timing, idle speed, and EGR flow for the emission system. Most DVOMs do not have the capability of measuring frequency. An oscilloscope would show you the signal and allow you to see it change frequency when you changed the pressure on it.

Exercise

1. If the combustion process were perfect, what two compounds would be the only product of this combustion?
2. What are the five general systems that are used for control of harmful emissions?

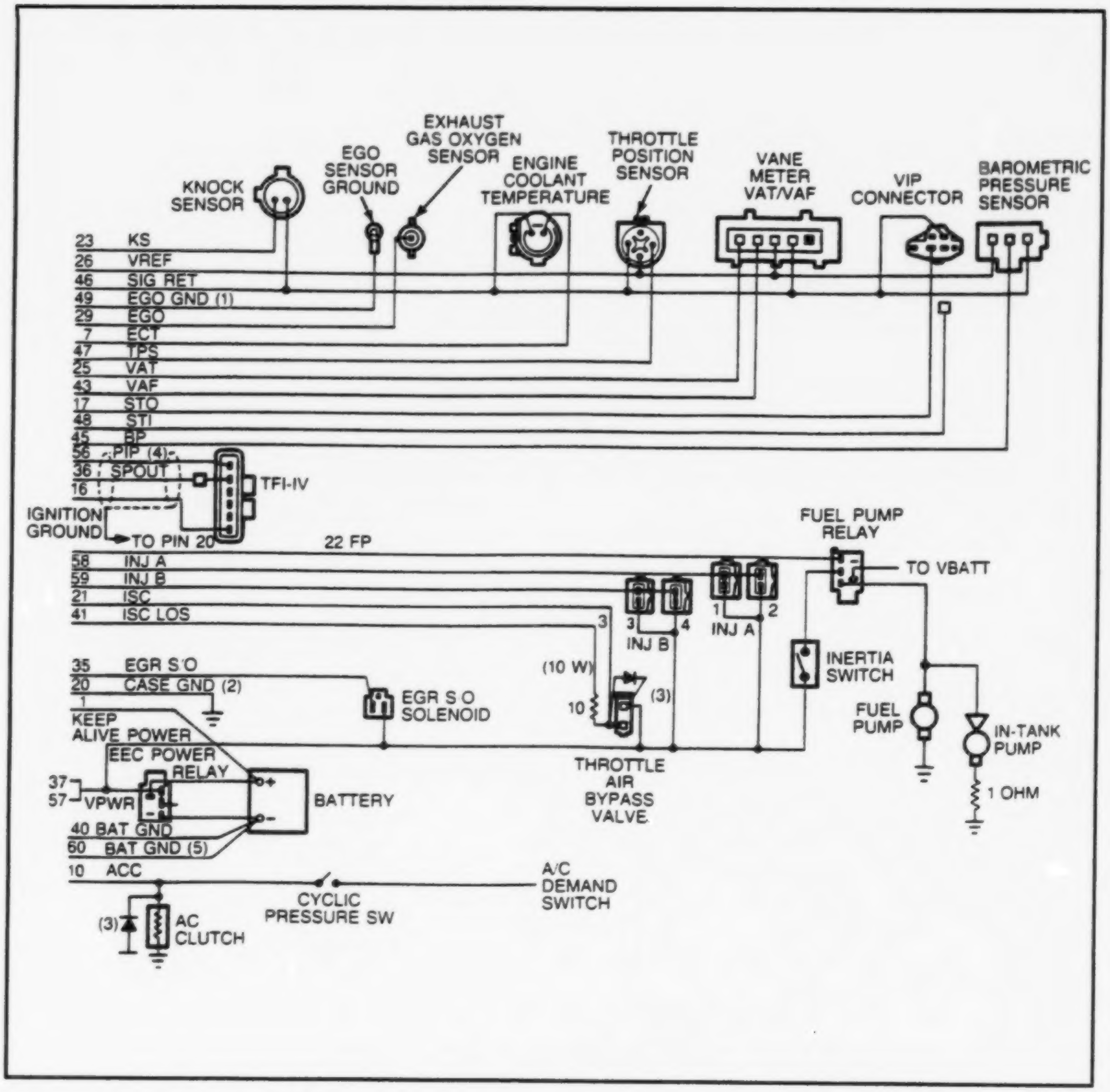

KNOCK SENSOR
EGO SENSOR GROUND
EXHAUST GAS OXYGEN SENSOR
ENGINE COOLANT TEMPERATURE
THROTTLE POSITION SENSOR
VANE METER VAT/VAF
VIP CONNECTOR
BAROMETRIC PRESSURE SENSOR
23 KS
26 VREF
46 SIG RET
49 EGO GND (1)
29 EGO
7 ECT
47 TPS
25 VAT
43 VAF
17 STO
48 STI
45 BP
56 PIP (4)
36 SPOUT
16
TFI-IV
IGNITION GROUND
TO PIN 20
22 FP
FUEL PUMP RELAY
TO VBATT
58 INJ A
59 INJ B
21 ISC
41 ISC LOS
3
3
4
INJ B
1
2
INJ A
INERTIA SWITCH
35 EGR S O
20 CASE GND (2)
1
KEEP ALIVE POWER
EGR S O SOLENOID
(10 W)
10
(3)
THROTTLE AIR BYPASS VALVE
FUEL PUMP
IN-TANK PUMP
1 OHM
EEC POWER RELAY
37
57
VPWR
BATTERY
40 BAT GND
60 BAT GND (5)
10 ACC
CYCLIC PRESSURE SW
A/C DEMAND SWITCH
(3)
AC CLUTCH

Fig. 6. Typical 2.3L turbo electrical schematic. (Courtesy of Ford Motor Company)

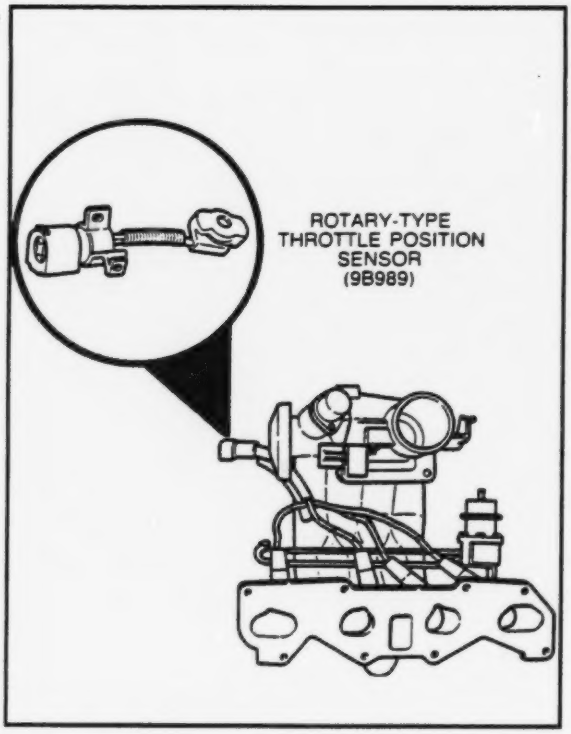

ROTARY-TYPE
THROTTLE POSITION
SENSOR
(9B989)

Fig. 7. Rotary-type throttle position sensor. (Courtesy of Ford Motor Company)

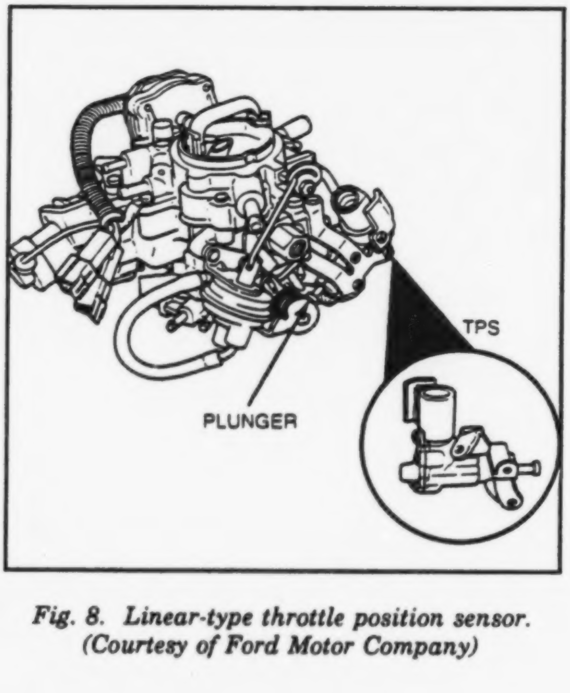

TPS
PLUNGER

Fig. 8. Linear-type throttle position sensor. (Courtesy of Ford Motor Company)

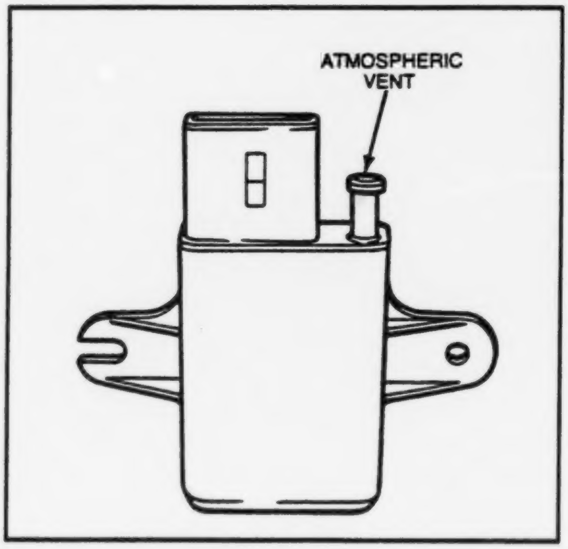

ATMOSPHERIC
VENT

Fig. 9. BAP Sensor. (Courtesy of Ford Motor Company)

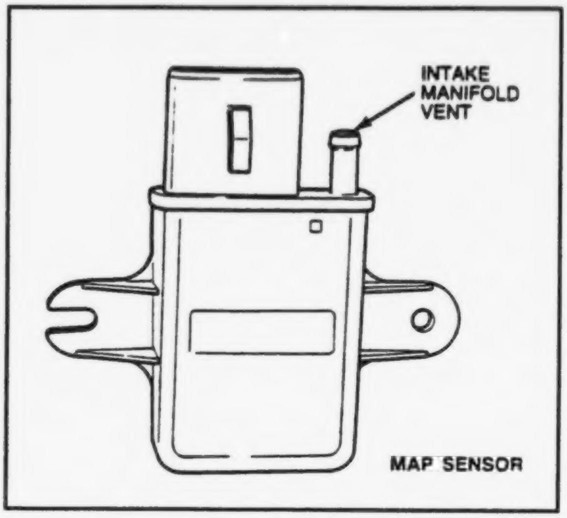

INTAKE
MANIFOLD
VENT
MAP SENSOR

Fig. 10. MAP sensor. (Courtesy of Ford Motor Company)

3. Which system is used to reduce the amount of nitrogen oxides in the exhaust gases?

4. Which sensor is critical to the operation of the feedback network or closed loop operation?

5. What engine condition will generate carbon monoxide?

F-4 Emission Control Systems

Laboratory Experiment

Essential Elements: (gg)(1, 2, 4, and 5)

Objective

Students will determine if the potentiometer they are using in this lab is linear or nonlinear.

Equipment

1 potentiometer
1 DVOM
Paper, wooden pencil, or other stick for a pointer

Procedure

To determine if the pot is linear or nonlinear, you will plot the change in resistance against the change in position of the wiper or the control on the pot. If the line on the graph that you plot is a straight line, the pot is linear. If the line is curved, the pot is nonlinear.

1. Start by attaching a wooden pencil or other suitable pointer to the shaft on the potentiometer so you can read the position of the control. Attach it with string or a rubber band so that it does not move and give you an erroneous reading.

2. Place a piece of paper under the pot, and move the control all the way in both directions, noting the size of the arc that it moves through. Draw a circle showing this amount of arc, and divide this arc into ten *equal* sections.

3. Take another piece of paper, and draw a horizontal line. On the right end of this line, draw a vertical line. Label the horizontal line as the control movement, and divide it into ten sections.

4. Measure the total resistance of the pot by using your DVOM and reading between the two outside terminals.

5. Put the maximum resistance reading from step 4 at the top of the vertical line. Divide the vertical line into ten sections, and label each section with the resistance. The bottom of the vertical line should show 0 Ω. The first section up should show 10% of the total resistance. The next section should show 20% of the total resistance.

6. Now adjust the control of the pot to the first segment, and read the resistance. If the resistance is high, use the other outside terminal. Make a mark on your graph to show where the resistance and the position lines would cross. Do this with the other nine segments on your graph.

If the line that connects these ten marks on your graph is mostly a straight line, the pot is a linear pot. If the line has a strong curve to it, the pot is nonlinear. The most common nonlinear pot has a logarithmic taper to it, or it changes at a logarithmic rate.

Unit
G
Vehicle Control Systems

G-1 Cruise Control
G-2 Electronic Gearshift Transmissions
G-3 Antilock Brake Systems

441

G - 1

Cruise Control

Essential Elements: (gg)(1, 2, and 4)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *cruise control on a typical automobile*
- *the electronic controls on an automatic transmission*
- *the electronic controls on the braking system in a typical automobile*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how a typical speed control system controls the vehicle speed*
- *explain where the speed control system obtains its input data*

Speed Control System

In the late 1960s, many of the luxury cars had speed control systems either as an option or as standard equipment. In the late '70s and early '80s, most of the speed control systems became electronically controlled. The basic parts of a typical speed or cruise control system are shown in figure 1.

The driver activates the system by turning ON the ON/OFF switch on the left side of the steering wheel (fig. 2). There is a minimum speed for the system to work called the MSLO (Minimum Speed LOckout). Ford has an MSLO of 30 mph.

Once the system is ON, the driver, in a Ford vehicle, can then set the speed by touching the SET/ACCEL switch or the COAST switch. Other manufacturers may label these switches in a different manner, but their system will be similar. Momentarily touching one of these switches results in the car maintaining its current speed provided it is over the MSLO. This speed will be maintained until the driver presses and holds the SET/ACCEL button to reach a higher speed, presses the brake or clutch, or turns the system off. Pressing the brake or clutch or turning the system off releases the speed control.

When the driver presses and holds the SET/ACCEL button, the system will increase the speed of the car and maintain this new speed when the button is released. When the brake or clutch pedal is depressed, the system drops control of the speed of the car, but maintains the speed information in memory. The RESUME button uses this memory to bring the car back up to the old speed and maintain it there.

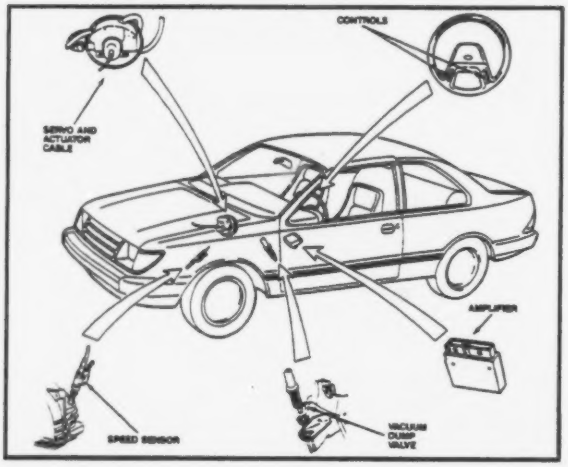

CONTROLS
SERVO AND ACTUATOR CABLE
AMPLIFIER
SPEED SENSOR
VACUUM DUMP VALVE

Fig. 1. Speed control with resume components–general location. (Courtesy of Ford Motor Company)

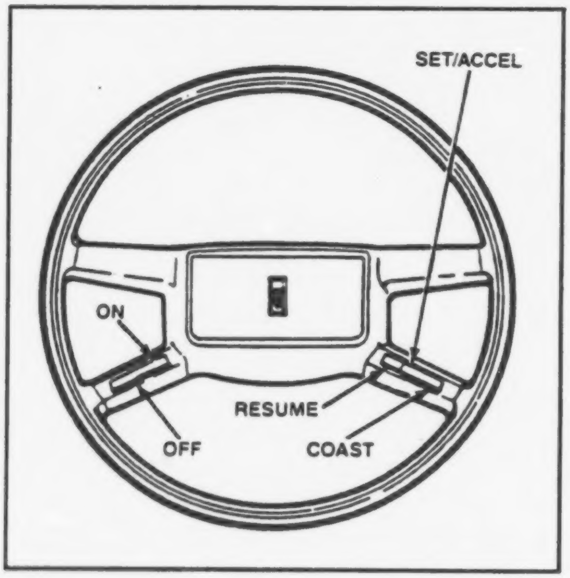

SET/ACCEL
ON
RESUME
OFF
COAST

Fig. 2. Driver controls. (Courtesy of Ford Motor Company)

Speed Control Operation

The driver controls the speed control system by using three switches that can be built into the steering wheel or, on some cars, the turn signal arm. A single wire leads from the switch assembly to the speed control amplifier (fig. 3).

Each of the switches will ground a different value resistor, resulting in a different voltage level sent to the amplifier on the single wire. Figure 4 shows how these resistors are connected in the circuit.

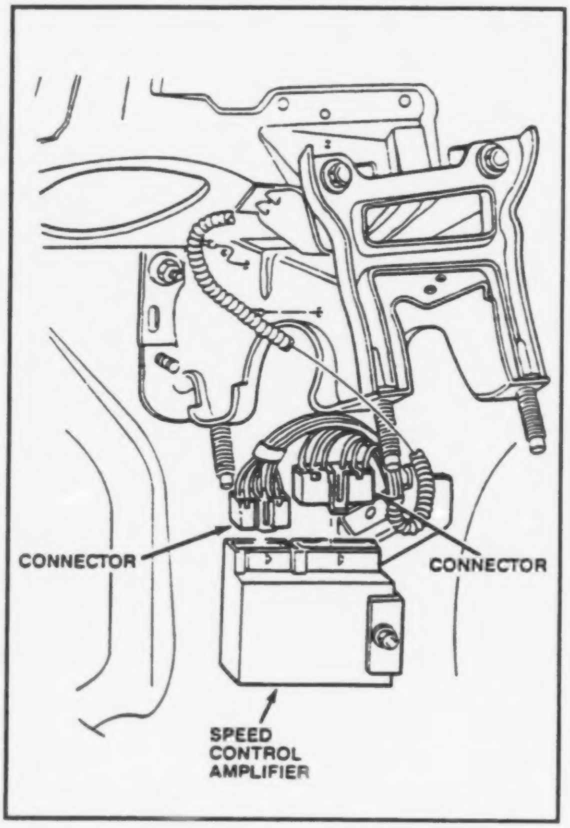

CONNECTOR
CONNECTOR
SPEED CONTROL AMPLIFIER

Fig. 3. Amplifier. (Courtesy of Ford Motor Company)

The large line connected to the top of the horn switch is connected to a high impedance source of battery voltage. The high impedance means that there is the equivalent of a resistor in series with this line. If you assume that the impedance is 1 kΩ or that the equivalent of a 1 kΩ resistor is in series with the battery voltage, you can see how different voltages will be sent to the amplifier.

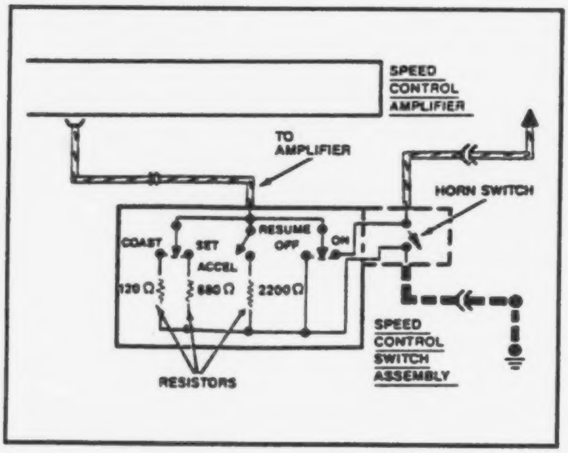


Fig. 4. Switch wire. (Courtesy of Ford Motor Company)

For figure 4, assume that the ON switch is closed and the COAST switch is closed. We now have the 12-volt battery voltage in series with the 1 kΩ impedance and the 120 Ω resistor with a line coming from a point between these two resistances back to the amplifier. The total resistance is 1,120 Ω, which can be divided into the 12-volt battery voltage source to give 10.7 mA of current. This current times the 120 Ω will give a voltage drop of about 1.3 volts, which is the voltage sent to the amplifier. Working this same example for the RESUME switch instead of the COAST switch will give 8.25 volts sent to the amplifier.

The amplifier is a computer module that takes the inputs from the driver-controlled switches, the speed of the car, and the throttle position sensor to control the speed using the vacuum servo. Figure 5 shows all of the inputs and outputs to the amplifier. Notice the switch inputs from the clutch and stoplights.

The vacuum servo (fig. 6) operates the throttle to control the speed of the car. The vacuum diaphragm in the servo changes the throttle position according to the amount of vacuum that is applied to it. The amount of vacuum is controlled by two solenoid valves (fig. 7). These valves are controlled by the amplifier.

The vent solenoid releases vacuum, and the vacuum solenoid (fig. 7) will take vacuum from the engine. During normal speed control, these valves are continually opening and closing to maintain speed by adjusting the throttle.

The throttle position sensor (fig. 7) provides feedback information on the position of the throttle. This feedback information is one of the inputs used by the amplifier.

The movement of the diaphragm in the servo is transmitted along the actuator cable (fig. 8). This cable may have a hardshell end or the bead end, shown in figures 9 and 10. The type of end will depend on the type of throttle body used on that make of car.

The speed sensor is located in different places on different cars. On some cars it may be located at the transaxle where the speedometer cable is connected (fig. 11). In other cars, the speed sensor is located on the speedometer cable (fig. 12).

The stoplamp switch senses the signal to the stoplights when the brakes are applied. This switch is usually mounted on the brake light switch (fig. 13). If there is an open in the circuit to the light bulbs or the bulbs

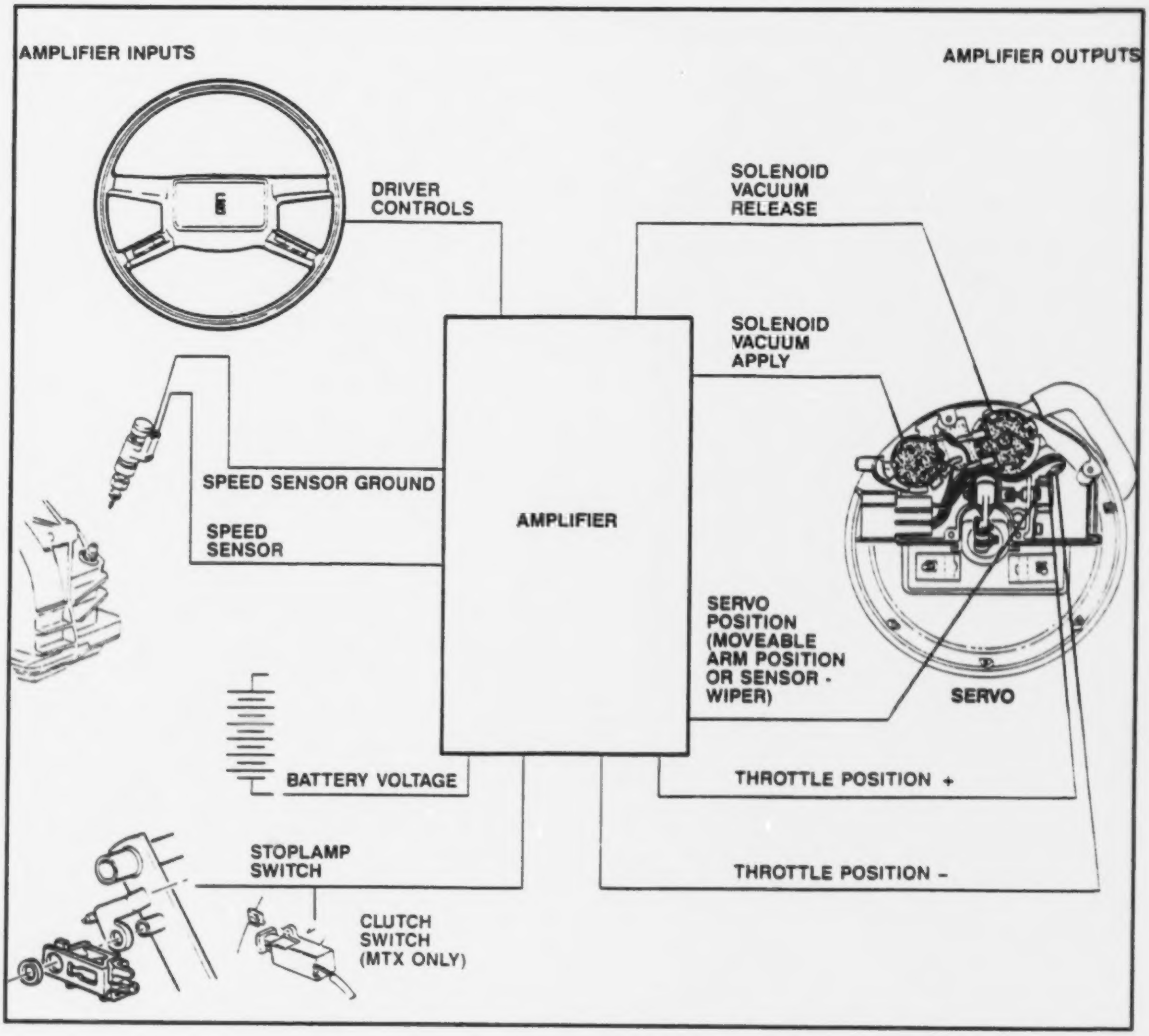

AMPLIFIER INPUTS
AMPLIFIER OUTPUTS
DRIVER CONTROLS
SOLENOID VACUUM RELEASE
SOLENOID VACUUM APPLY
SPEED SENSOR GROUND
SPEED SENSOR
AMPLIFIER
SERVO POSITION (MOVEABLE ARM POSITION OR SENSOR - WIPER)
SERVO
BATTERY VOLTAGE
THROTTLE POSITION +
STOPLAMP SWITCH
THROTTLE POSITION -
CLUTCH SWITCH (MTX ONLY)

Fig. 5. Amplifier inputs and outputs. (Courtesy of Ford Motor Company)

are burnt, the speed control system will not work.

Vehicles with a standard transmission have a clutch switch to signal the amplifier when the clutch is engaged. The signal from this switch is sent along the same line as the brake light switch, and the amplifier considers it the same signal.

When either the brake or clutch switch is activated, the amplifier stops controlling the speed and stores the speed data in memory. The RESUME switch can be used to bring the car back to its original speed as long as the memory is retained. If the ignition is turned OFF or the speed control OFF button is pushed, the memory will be lost.

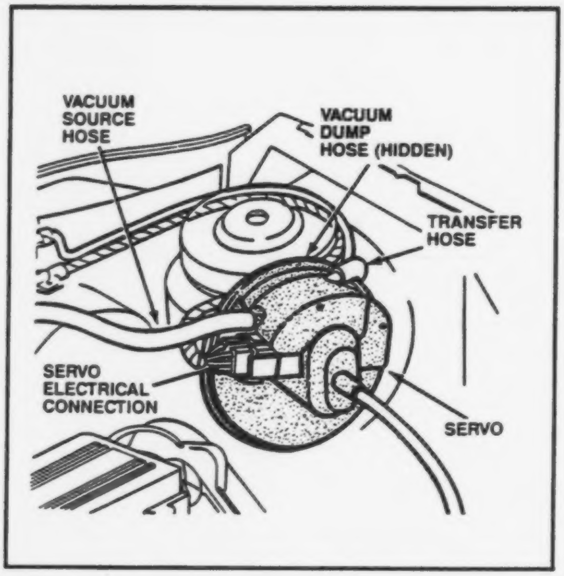

VACUUM SOURCE HOSE
VACUUM DUMP HOSE (HIDDEN)
TRANSFER HOSE
SERVO ELECTRICAL CONNECTION
SERVO

Fig. 6. Vacuum servo. (Courtesy of Ford Motor Company)

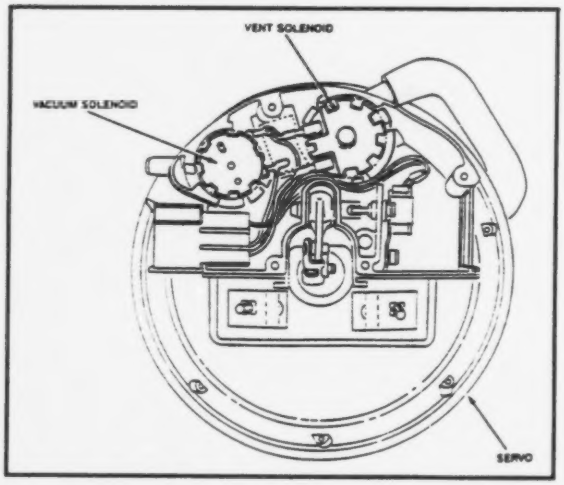

VENT SOLENOID
VACUUM SOLENOID
SERVO

Fig. 7. Servo solenoid valves and throttle position sensor. (Courtesy of Ford Motor Company)

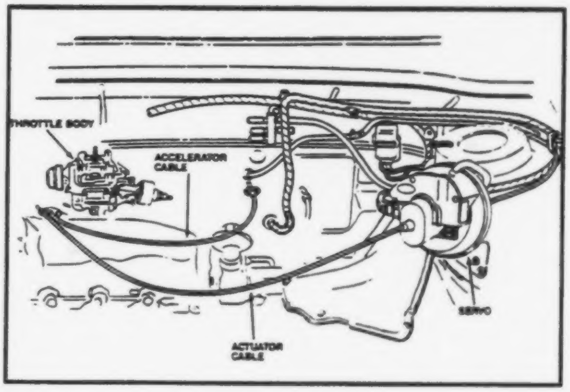

THROTTLE BODY
ACCELERATOR CABLE
SERVO
ACTUATOR CABLE

Fig. 8. Actuator cable. (Courtesy of Ford Motor Company)

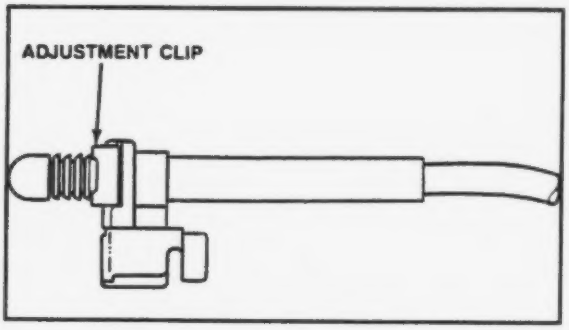

ADJUSTMENT CLIP

Fig. 9. Hardshell end. (Courtesy of Ford Motor Company)

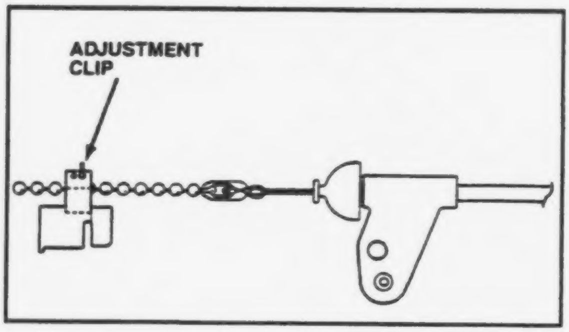

ADJUSTMENT CLIP

Fig. 10. Bead end. (Courtesy of Ford Motor Company)

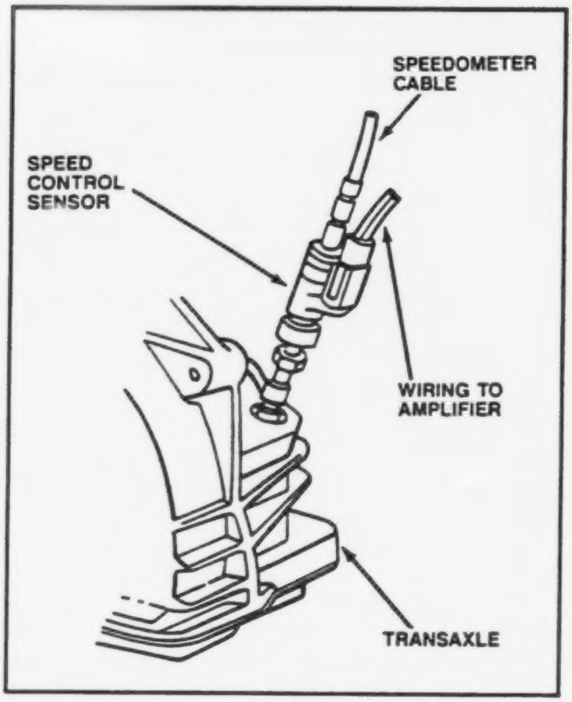

SPEEDOMETER CABLE
SPEED CONTROL SENSOR
WIRING TO AMPLIFIER
TRANSAXLE

Fig. 11. Vehicle speed sensor. (Courtesy of Ford Motor Company)

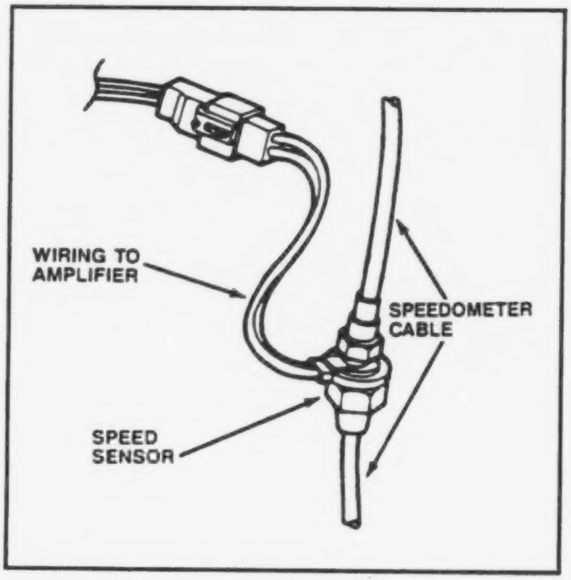

WIRING TO AMPLIFIER
SPEEDOMETER CABLE
SPEED SENSOR

Fig. 12. Speed sensor on speedometer cable. (Courtesy of Ford Motor Company)

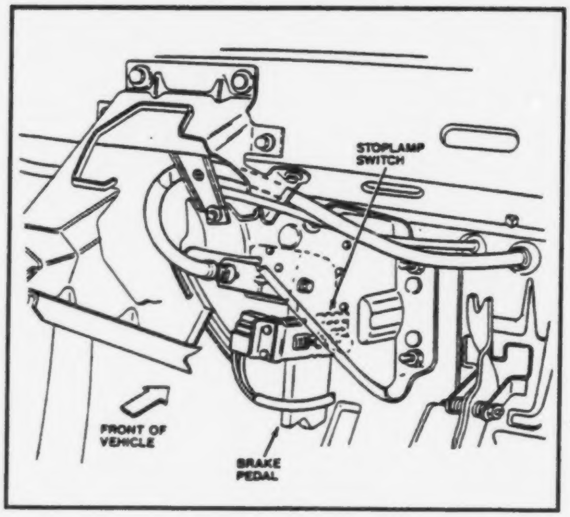

STOPLAMP SWITCH
FRONT OF VEHICLE
BRAKE PEDAL

Fig. 13. Stoplamp switch. (Courtesy of Ford Motor Company)

As an additional safety measure, most speed control systems have a vacuum dump valve which will dump the vacuum when the brake pedal is pressed. There is an electrical switch on the brake light switch and an additional mechanically released valve to dump the vacuum in the servo. Figure 14 shows the connect for the vacuum dump valve.

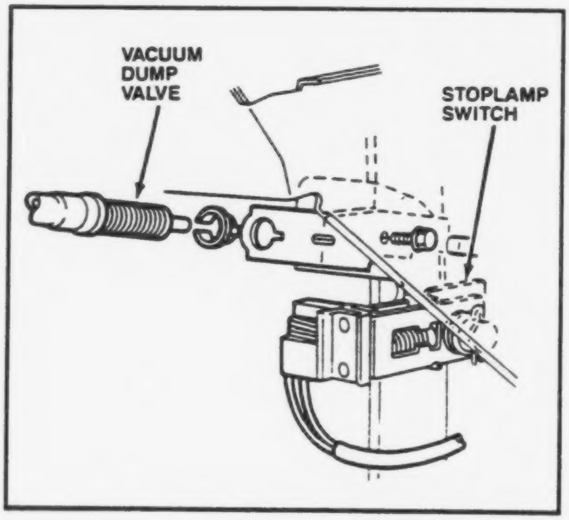

VACUUM DUMP VALVE
STOPLAMP SWITCH

Fig. 14. Vacuum dump valve. (Courtesy of Ford Motor Company)

The Ford company puts its driver controls on the steering wheel. To avoid extra slip rings for the speed control, the battery supply through the horn relay coil is used to supply the voltage for the speed control switches, as shown in figure 15. This horn relay coil provides the resistance that we were working with in our previous example.

Vehicles equipped with a turbocharger will not have any vacuum during the operation of the turbocharger. To maintain the vacuum for the speed control system, an additional source of vacuum has been created. When the car is under normal (nonboost) condition, the vacuum is obtained from the manifold through the #2 check valve, as shown in figure 16. The #1 check valve blocks the vacuum from leaking out during this normal operation.

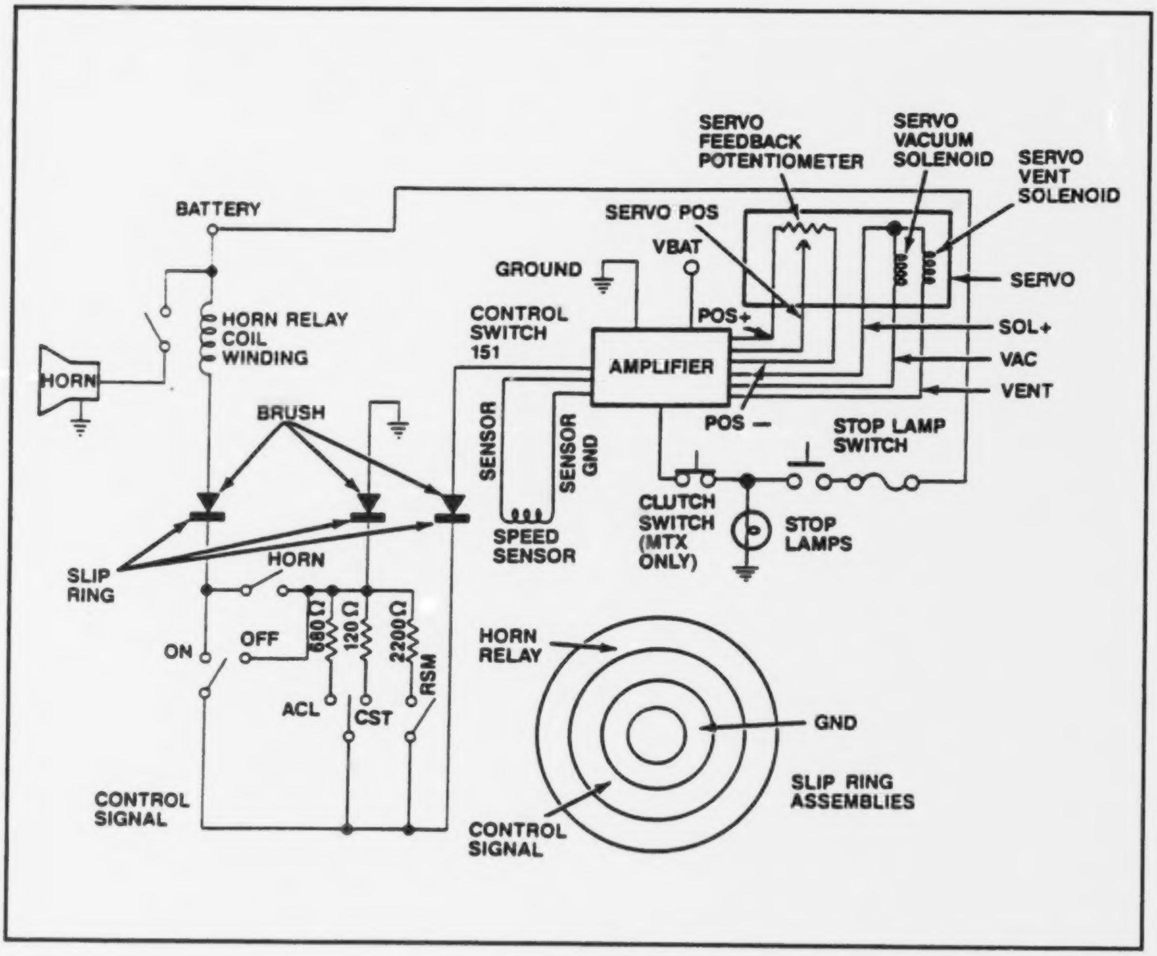

SERVO FEEDBACK POTENTIOMETER
SERVO VACUUM SOLENOID
SERVO VENT SOLENOID
BATTERY
SERVO POS
VBAT
GROUND
SERVO
CONTROL SWITCH 151
POS+
SOL+
HORN RELAY COIL WINDING
AMPLIFIER
VAC
HORN
VENT
BRUSH
SENSOR
SENSOR GND
POS −
STOP LAMP SWITCH
CLUTCH SWITCH (MTX ONLY)
STOP LAMPS
SPEED SENSOR
SLIP RING
HORN
680 Ω
120 Ω
2200 Ω
ON
OFF
ACL
CST
RSM
HORN RELAY
GND
SLIP RING ASSEMBLIES
CONTROL SIGNAL
CONTROL SIGNAL

Fig. 15. Horn relay/speed control wiring. (Courtesy of Ford Motor Company)

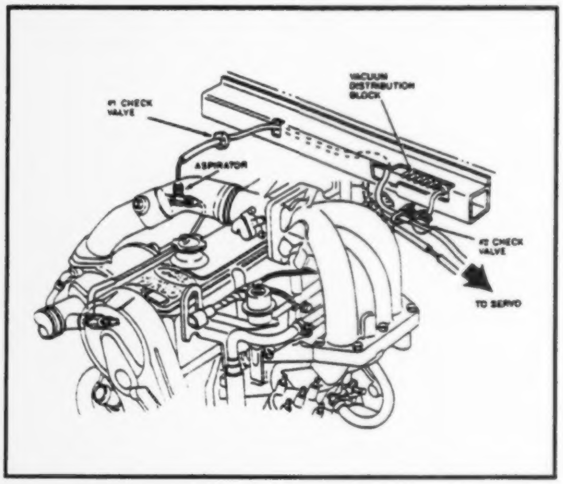


Fig. 16. Aspirator and check valves. (Courtesy of Ford Motor Company)

When the vehicle operates with the turbocharger, there is a strong flow of air coming from the compressor side of the turbocharger. This strong flow of air is used to create a vacuum using the venturi principle, as shown in figure 17. This vacuum travels through check valve #1 and is blocked by check valve #2.

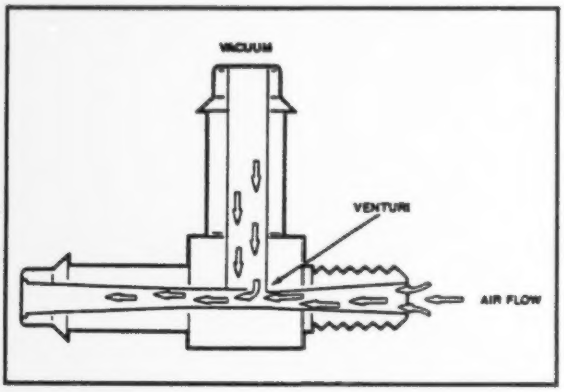


Fig. 17. Aspirator operation. (Courtesy of Ford Motor Company)

Some manufacturers are now including the functions performed by the amplifier in the electronic engine control module or the computer that controls the engine. The throttle position sensor that is used for an input to the EEC also provides the information for the speed control. Combining the functions of the speed control and engine control into one computer module has allowed engineers to add system diagnostics to the speed control as well as the engine control.

Exercise

1. What is the MSLO for most Ford cars?
2. If a driver momentarily presses the brake while operating the cruise control, what button can the driver press to regain and maintain the original speed set on the cruise control?
3. In figure 18, if the HORN RELAY COIL is 800 Ω in figure 18 and the COAST resistor is 680 Ω, what will the voltage be at the SCCS connection to the EEC IV PROCESSOR? Assume that the V BAT is 12 volts and that all other switches are open except the ON switch.
4. What is the voltage at the SCCS connection to the EEC IV PROCESSOR in figure 18 when the HORN switch is closed?
5. In figure 18, what is the voltage at connection B00 when the stoplamp switch is open and closed?

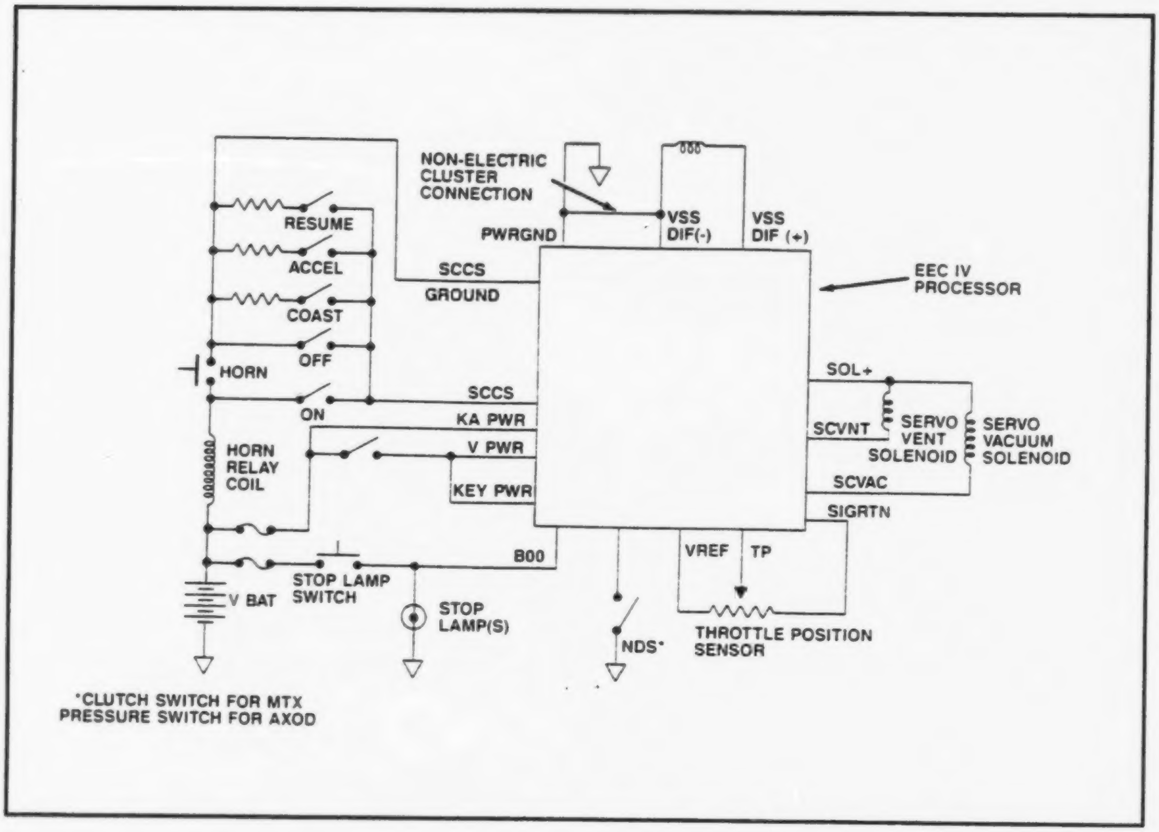

NON-ELECTRIC CLUSTER CONNECTION
PWRGND
VSS DIF(-)
VSS DIF (+)
EEC IV PROCESSOR
RESUME
ACCEL
COAST
OFF
HORN
ON
SCCS
GROUND
SCCS
KA PWR
V PWR
KEY PWR
HORN RELAY COIL
B00
V BAT
STOP LAMP SWITCH
STOP LAMP(S)
NDS*
VREF
TP
THROTTLE POSITION SENSOR
SOL+
SCVNT
SERVO VENT SOLENOID
SERVO VACUUM SOLENOID
SCVAC
SIGRTN
*CLUTCH SWITCH FOR MTX
PRESSURE SWITCH FOR AXOD

Fig. 18. IVSC EEC wiring diagram. (Courtesy of Ford Motor Company)

G-1 Cruise Control

Laboratory Experiment

Essential Elements: **(gg) (1, 2, and 4)**

Objective

This lab will help you understand the driver-controlled switches that control the speed control system.

Equipment

1 6-volt voltage source (batteries and battery holder)
1 120 Ω resistor
1 680 Ω resistor
1 2.2 kΩ resistor
1 1 kΩ resistor
1 DVOM

Procedure

Examine the schematic in figure 1, and notice the location of the V BAT, HORN RELAY COIL, RESUME resistor, ACCEL resistor, COAST resistor, the OFF switch, the ON switch, and the SCCS GROUND. Also notice the SCCS line which goes into the EEC IV PROCESSOR (computer module).

1. Redraw the part of the circuit in figure 1 that includes the components listed above. Leave the circuit open at the HORN switch. Do not include the two fuses, the STOPLAMP SWITCH, or the KA PWR and V PWR lines. Where the SCCS line connects to the EEC, show that line connected to your DVOM with the negative lead of the DVOM connected to ground. Show the V BAT as your 6-volt battery source. The SCCS GROUND will connect back to the negative terminal on your 6-volt supply.

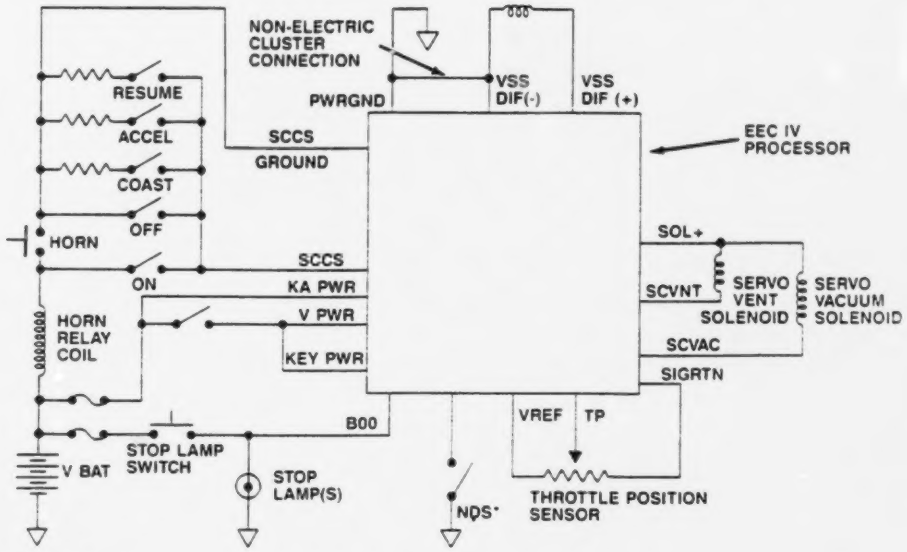
2. Label the resistors on your drawing showing 120 Ω for COAST, 680 Ω for ACCEL, and the 2.2 kΩ for RESUME. Make a notation that the HORN RELAY COIL will be replaced with a 1 kΩ resistor.

3. Use your components to build the circuit that you have just drawn.

4. Make a chart to record the voltage levels for the OFF switch, COAST, ACCEL, and RESUME switches. You can just connect and disconnect each resistor with your jumper leads to simulate the switches. Calculate and record the voltages that you expect to read when you measure these voltages.

5. Measure and record the voltage levels for each of the switch positions on your chart. Compare these measurements with the calculated values. Go back over your calculations if there is a significant difference between the calculated value and the measured value.

6. Measure these voltages again with the 1 kΩ resistor both open and shorted to simulate two fault conditions.


NON-ELECTRIC
CLUSTER
CONNECTION
PWRGND
VSS
DIF(-)
VSS
DIF (+)
RESUME
ACCEL
COAST
OFF
HORN
ON
SCCS
GROUND
SCCS
KA PWR
V PWR
KEY PWR
EEC IV
PROCESSOR
SOL+
SCVNT
SERVO
VENT
SOLENOID
SERVO
VACUUM
SOLENOID
SCVAC
SIGRTN
HORN
RELAY
COIL
B00
VREF
TP
V BAT
STOP LAMP
SWITCH
STOP
LAMP(S)
NDS*
THROTTLE POSITION
SENSOR

*CLUTCH SWITCH FOR MTX
PRESSURE SWITCH FOR AXOD

Fig. 1. IVSC EEC wiring diagram. (Courtesy of Ford Motor Company)

G-2

Electronic Gearshift Transmissions

Essential Elements: (gg)(1, 2, and 4)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *cruise control on a typical automobile*
- *the electronic controls on an automatic transmission*
- *the electronic controls on the braking system in a typical automobile*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how the computer module controls the shift points on a typical transaxle*
- *explain how problems affect the operation of the transaxle*

Transaxle Operation

Most automobiles are becoming front wheel drive with the transmission and front axle combined into one unit. This arrangement results in better fuel economy and is cheaper to build. The transaxle that you are going to study is a four-speed, computer-controlled unit.

The shift indicator for this transaxle is shown in figure 1 with the indicator in the PARK position.

The engine can only be started when the vehicle is in PARK or NEUTRAL. In these two positions, there is no power through the transmission that would cause the vehicle to move. In the NEUTRAL position, the vehicle will roll; and in the PARK position, there is a park rod assembly that will result in the park pawl engaging the lugs in the rear carrier assembly. This will lock up the output shaft to the transaxle case.

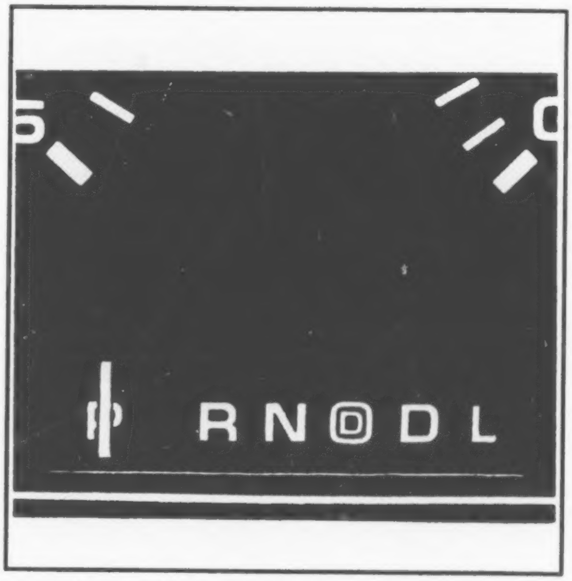


Fig. 1. Neutral and park. (Courtesy of Chrysler Motor Company)

The OD position on the gearshift selector is the normal drive position for the transmission. When the gearshift lever is moved to this position, with the engine running, the transaxle automatically shifts into first gear. As the driver accelerates, the vehicle reaches a particular speed and engine load where the transaxle automatically shifts to second gear. This will continue all the way to fourth gear.

Once the vehicle is in fourth gear, the torque converter will lock up if the load and speed conditions are correct. This action is often smooth enough that the driver does not notice the change.

At speeds above 79 mph, the transaxle will not downshift when the driver presses the accelerator pedal all the way. At lower speeds, the transaxle will downshift depending on vehicle speed and throttle position.

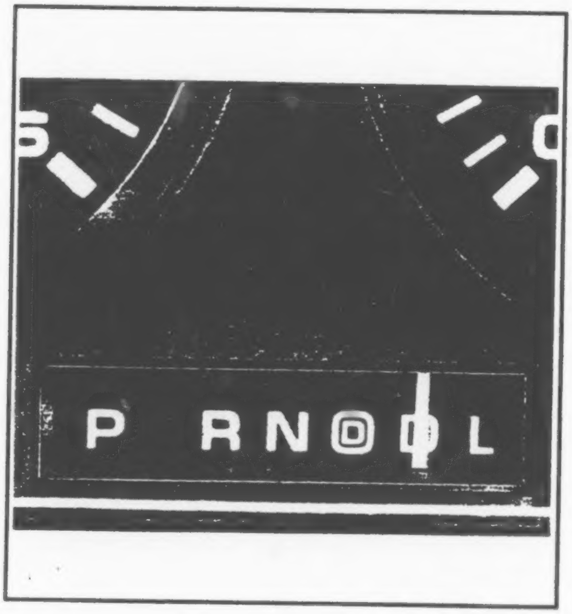


Fig. 2. Drive "D." (Courtesy of Chrysler Motor Company)

If the driver moves the gearshift lever from the OD position to the D position, as shown in figure 2, and while traveling in fourth gear, the transaxle will immediately shift down to third gear.

When the driver moves the gearshift lever from OD to L while traveling in fourth gear at highway speeds, the transaxle will automatically downshift at higher speeds, allowing maximum use of the engine to slow the vehicle down.

While driving on hilly roads or on steep grades, the driver can shift to D, and the transaxle will not shift higher than third gear and will lock up in third gear when the speed and load conditions are correct.

Driving in L is similar to driving in D except that the transaxle will shift at higher engine speeds. The transaxle will shift all the way to third gear and only shift up when the engine is close to operating at its maximum speed.

Transaxle Components

Notice the turbine speed sensor and output speed sensor in figure 3. The solenoid assembly and the neutral safety switch are located near the bottom along with the PRNDL switch and the pressure switches.

The transaxle controller, which is the computer module that controls the transaxle, is mounted in a protected area such as under the dash in some vehicles. The controller uses all of the inputs from the transaxle plus information from the throttle sensor, coolant temperature sensor, and engine speed, battery temperature, and brake switch sensors. The controller only controls the four solenoids to control shifting and lockup on the transaxle.

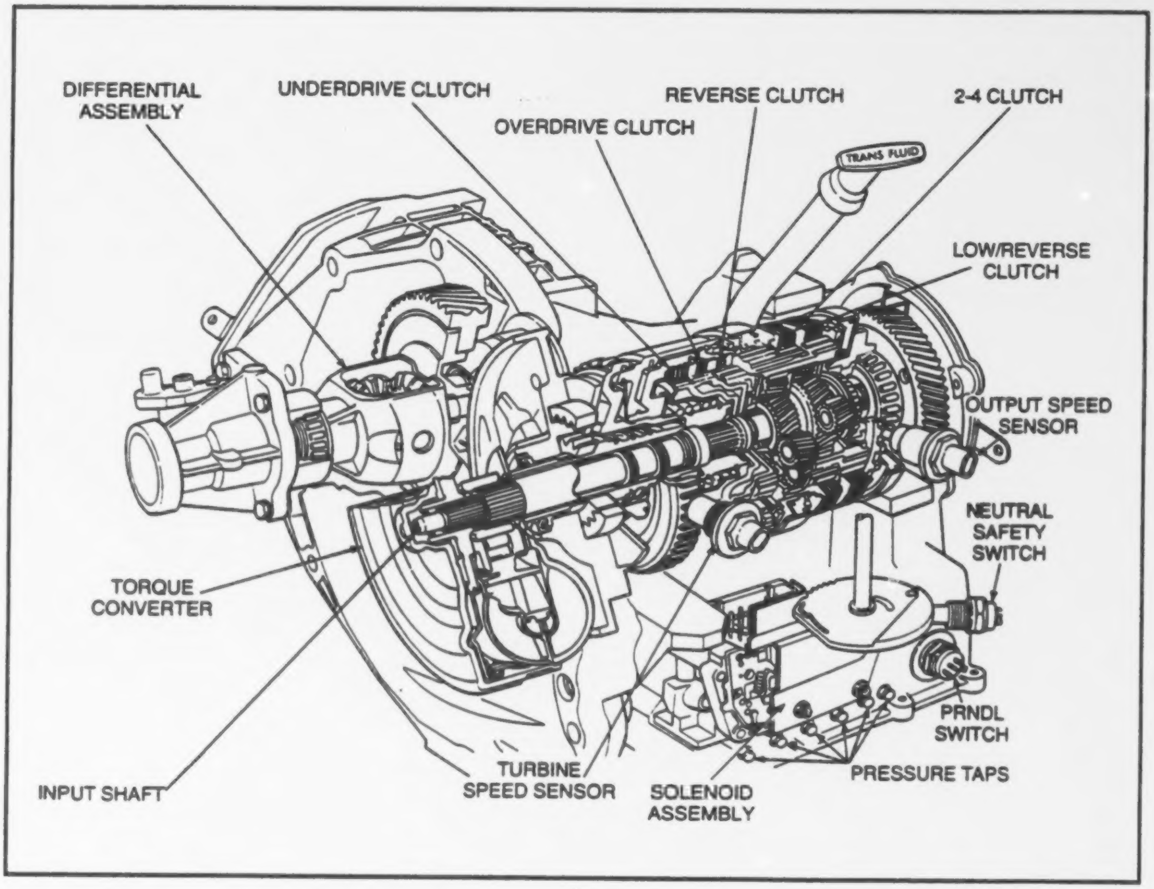

DIFFERENTIAL ASSEMBLY
UNDERDRIVE CLUTCH
REVERSE CLUTCH
2-4 CLUTCH
OVERDRIVE CLUTCH
TRANS FLUID
LOW/REVERSE CLUTCH
OUTPUT SPEED SENSOR
NEUTRAL SAFETY SWITCH
TORQUE CONVERTER
PRNDL SWITCH
PRESSURE TAPS
INPUT SHAFT
TURBINE SPEED SENSOR
SOLENOID ASSEMBLY

Fig. 3. Electronic gearshift transaxle components (Courtesy of Chrysler Motor Company)

Transaxle Electronic Control

Using an electronic control system to shift gears and control lockup on the transaxle has resulted in a smoother, more efficient transaxle. The computer module has the ability to learn and correct for engine performance and friction in the unit. If battery power is lost, the memory will be lost, although it will only take about 10 shifts to relearn and regain the memory.

The computer controller may use up to 12 different sensor inputs. Many of these sensor inputs are used in common with other functions of the vehicle. The controller only controls four outputs for transaxle control. These four outputs are the solenoids that control shifting. In addition to these outputs, the controller will turn the solenoid relay on or off.

There are six pressure switches that monitor the solenoids. When a solenoid operates, the pressure confirms the operation and sends a feedback signal to the controller. The pressure switches are only used to confirm the proper operation of the transaxle and do not control anything.

This computer module, like the other modules, has a self-diagnostic feature. If a fault is found, it will store a fault code in memory. This fault code can be retrieved by plugging into the system with a diagnostic readout tool. This diagnostic readout tool is an electronic device that talks to the computer module.

If the fault condition on the transaxle is severe enough to endanger the whole transaxle or it is unsafe to drive, the computer will lock it into second gear. This will allow the driver to limp back home instead of being stranded.

On Board Self-Test

When the ignition is first turned on, the computer module or controller goes through a self-test. It starts by looking at the ignition voltage. If the ignition voltage is out of limits, the controller goes into default, which means that when the shift lever is moved to any forward gear, it automatically goes into second gear and stays there.

The controller checks the solenoid shutdown relay and solenoid assembly for proper operation. If they all check out, then the controller sends battery voltage to the solenoid shutdown relay. The relay will send voltage to the solenoid assembly to provide power for the solenoids and pressure switches.

If the controller runs into any problems and goes into default, it will de-energize the shutdown relay, which leaves the solenoids in their default condition. This results in the transaxle going into second gear when the shift lever is moved to OD, D, or L.

Solenoid Operation

The Chrysler transaxle uses four solenoids and five valves to operate the transaxle. These valves operate five transaxle clutches, lockup torque converter, and provide the oil for lubrication.

Figure 4 shows the transaxle operation in PARK or NEUTRAL. The dark area shows where the transaxle fluid is under high pressure. Notice the three valves on the right and the one on the bottom left.

Exercise

1. How many output solenoids does the controller control?
2. If the controller sees a serious fault with the transaxle system, what does it do?
3. After completing its checkout of the system, what is the first component that the controller sends battery voltage to?
4. What are the six pressure switches used for?

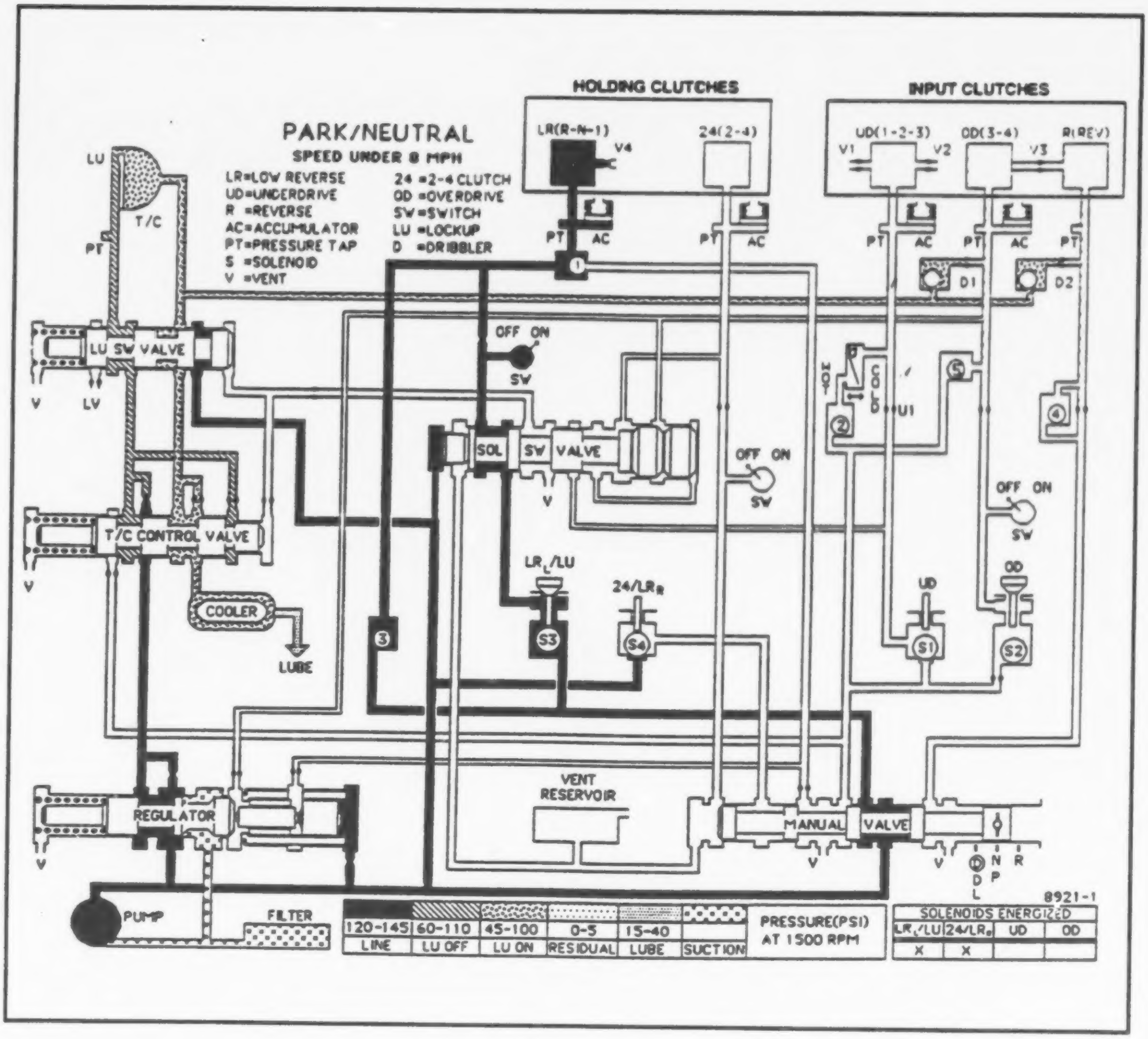

PARK/NEUTRAL
SPEED UNDER 8 MPH
LR=LOW REVERSE
UD=UNDERDRIVE
R =REVERSE
AC=ACCUMULATOR
PT=PRESSURE TAP
S =SOLENOID
V =VENT
24 =2-4 CLUTCH
OD =OVERDRIVE
SW=SWITCH
LU =LOCKUP
D =DRIBBLER
HOLDING CLUTCHES
LR(R-N-1)
24(2-4)
V4
INPUT CLUTCHES
UD(1-2-3)
OD(3-4)
R(REV)
V1
V2
V3
PT
AC
D1
D2
LU
T/C
LU SW VALVE
V
LV
OFF ON
SW
SOL
SW
VALVE
T/C CONTROL VALVE
COOLER
LUBE
LR$_L$/LU
24/LR$_R$
S3
S4
UD
S1
OD
S2
HOT
COLD
U1
①
②
③
④
⑤
VENT RESERVOIR
REGULATOR
MANUAL
VALVE
D
N
R
D
P
L
PUMP
FILTER
8921-1
120-145
60-110
45-100
0-5
15-40
LINE
LU OFF
LU ON
RESIDUAL
LUBE
SUCTION
PRESSURE(PSI) AT 1500 RPM
SOLENOIDS ENERGIZED
LR$_L$/LU
24/LR$_R$
UD
OD
X
X

Fig. 4. Schematic of transaxle in park and neutral. (Courtesy of Chrysler Motor Company)

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G-2 Electronic Gearshift Transmissions

Workbook

Essential Elements: (gg) (1, 2, and 4)

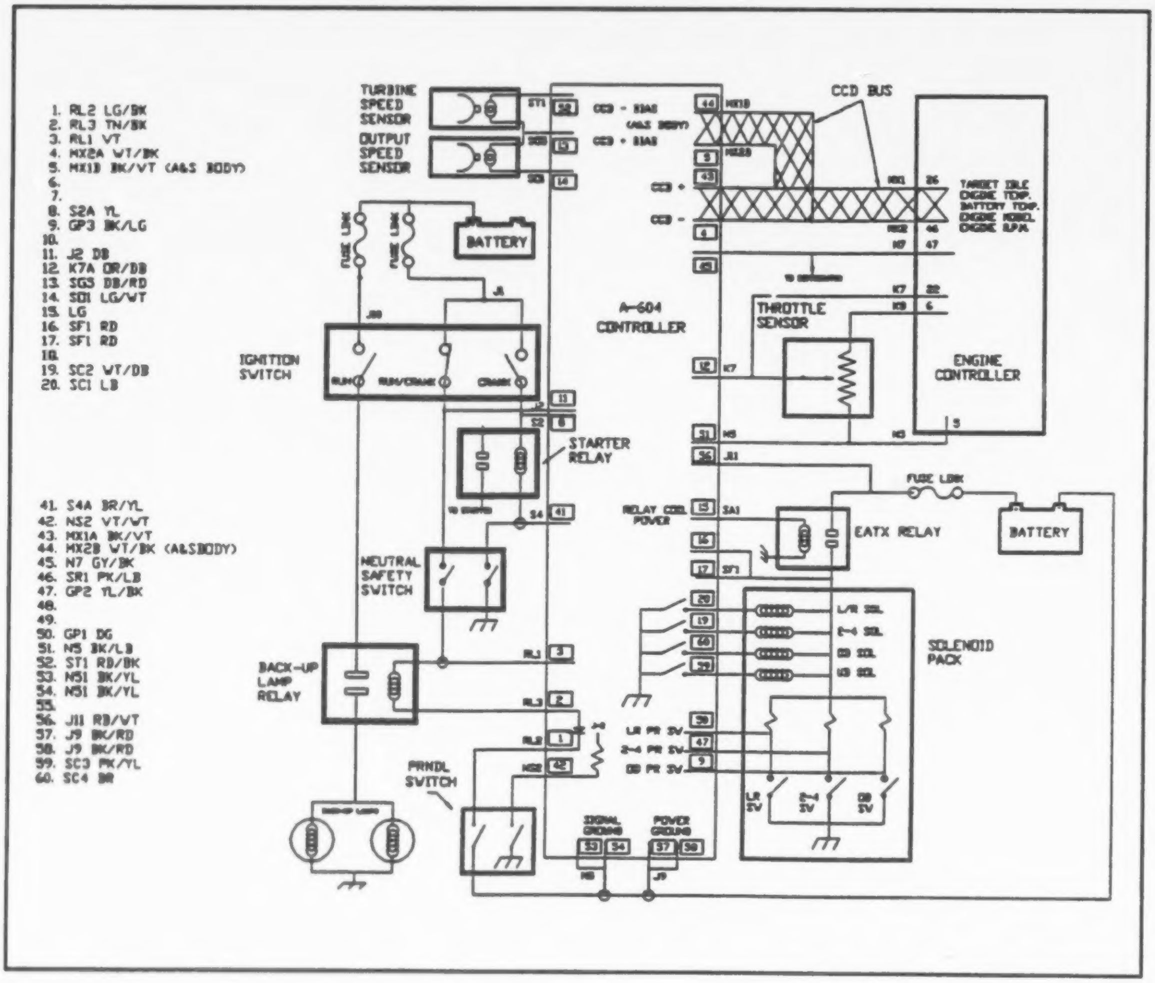

1. RL2 LG/BK
2. RL3 TN/BK
3. RL1 VT
4. MX2A WT/BK
5. MX1B BK/VT (A&S BODY)
6.
7.
8. S2A YL
9. GP3 BK/LG
10.
11. J2 DB
12. K7A OR/DB
13. SG3 DB/RD
14. SO1 LG/WT
15. LG
16. SF1 RD
17. SF1 RD
18.
19. SC2 WT/DB
20. SC1 LB
41. S4A BR/YL
42. NS2 VT/WT
43. MX1A BK/VT
44. MX2B WT/BK (A&SBODY)
45. N7 GY/BK
46. SR1 PK/LB
47. GP2 YL/BK
48.
49.
50. GP1 DG
51. N5 BK/LB
52. ST1 RD/BK
53. N51 BK/YL
54. N51 BK/YL
55.
56. J11 RB/VT
57. J9 BK/RD
58. J9 BK/RD
59. SC3 PK/YL
60. SC4 BR
TURBINE SPEED SENSOR
OUTPUT SPEED SENSOR
FUSE LINK
FUSE LINK
BATTERY
IGNITION SWITCH
RUN
RUN/CRANK
CRANK
STARTER RELAY
NEUTRAL SAFETY SWITCH
BACK-UP LAMP RELAY
PRNDL SWITCH
A-604 CONTROLLER
CCD BUS
CCD - BIAS
CCD + BIAS
CCD +
CCD -
TARGET IDLE
ENGINE TEMP.
BATTERY TEMP.
ENGINE MODEL
ENGINE RPM
THROTTLE SENSOR
ENGINE CONTROLLER
FUSE LINK
RELAY COIL POWER
EATX RELAY
BATTERY
L/R SOL
2-4 SOL
OD SOL
UD SOL
SOLENOID PACK
LR PR SW
2-4 PR SW
OD PR SW
LR SW
2-4 SW
OD SW
SIGNAL GROUND
POWER GROUND
52
15
14
44
5
43
6
12
11
8
41
51
56
15
16
17
20
19
60
59
3
2
1
42
50
47
9
53
54
57
58
26
46
47
22
6
5

Figure 1

Figure 1 shows the electrical drawing for the transaxle that you have been examining in the assignment. The CCD BUS is used to carry information from the engine controller or computer to the transaxle controller or computer.

1. There are two batteries shown in this schematic. Both of these batteries are actually the same battery that is drawn in two locations for simplicity. Locate

the battery on the left side near the top of the drawing. Write the names of the components that the current will pass through, when energizing the STARTER RELAY, from the battery to ground.

2. List the components that the current will pass through to light the backup lamps.

G-3

Antilock Brake Systems

Essential Elements: (gg)(1, 2, and 4)

Unit Objectives:

After completing this instructional unit, you will be able to explain the fundamentals of:

- *cruise control on a typical automobile*
- *the electronic controls on an automatic transmission*
- *the electronic controls on the braking system in a typical automobile*

Specific Objectives:

After completing this assignment, you will be able to:

- *explain how the computer module controls the application of braking force*
- *explain how the computer module receives the information necessary to make decisions resulting in control of the brakes*

Antilock Brake System Operation

The antilock brake system (ABS) controls the braking action of the wheels by adjusting the brake fluid pressure. This system controls the two front wheels individually and the rear wheels as a unit.

When the brakes are applied in a panic stop, the system controls the brake fluid pressure so the wheels do not lock up. During braking, the wheels will be turning at a slower speed than the movement of the car, resulting in "wheel slip." If the brakes lock up the wheel, we have 100% wheel slip. A good antilock brake system should keep the wheel slip between 8% and 35% for maximum stopping and control.

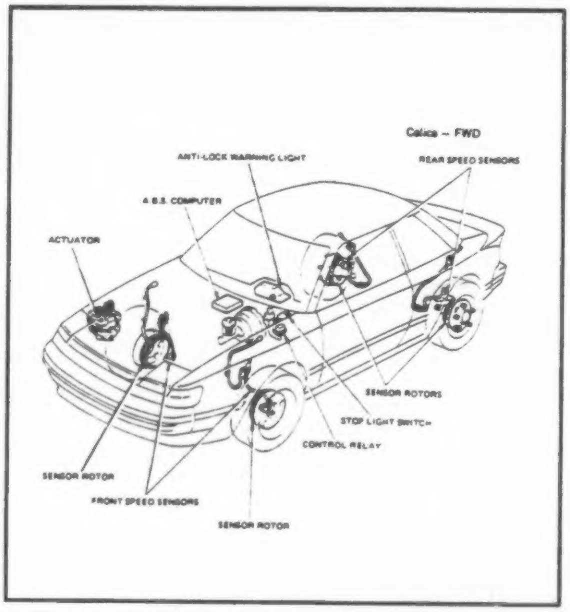

Calica – FWD
ANTI-LOCK WARNING LIGHT
REAR SPEED SENSORS
A.B.S. COMPUTER
ACTUATOR
SENSOR ROTORS
STOP LIGHT SWITCH
CONTROL RELAY
SENSOR ROTOR
FRONT SPEED SENSORS
SENSOR ROTOR

Fig. 1. Antilock brake system components. (Courtesy of Toyota)

During a panic stop, if the brakes lock up, all steering is lost, and the stopping ability is not as good as it would be without the lockup. Research has shown that around 10% wheel slippage will give maximum braking and maintain good steering control. Locking up the wheels can also damage or destroy the tires by wearing a flat spot on them.

The major components in the system are shown in figure 1. The ABS computer controls the system by using the inputs from the speed sensors on each of the wheels.

Figure 2 shows how the components are all connected together and to the computer. The actuator, shown to the right of the computer, receives signals from the computer to activate the solenoids that control the brake flüid pressure.

The speed sensors, which are located at each wheel, can use either the magnet in a coil system or the Hall effect switch system to determine the speed of the wheel. Remember that the previous section discussed both of these types of sensors.

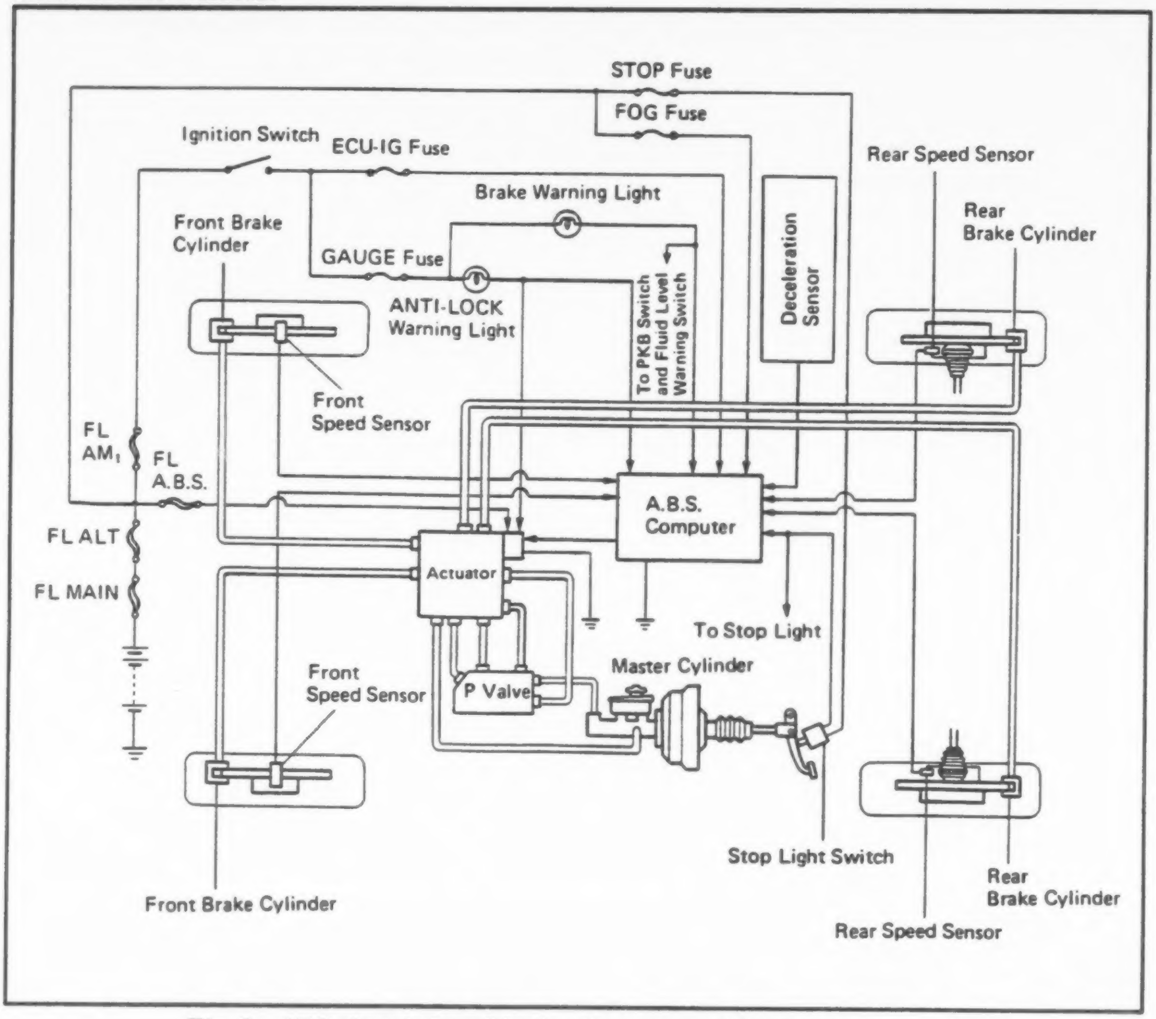

STOP Fuse
FOG Fuse
Ignition Switch
ECU-IG Fuse
Rear Speed Sensor
Brake Warning Light
Rear
Brake Cylinder
Front Brake
Cylinder
GAUGE Fuse
Deceleration
Sensor
ANTI-LOCK
Warning Light
To PKB Switch
and Fluid Level
Warning Switch
Front
Speed Sensor
FL
AM₁
FL
A.B.S.
A.B.S.
Computer
FL ALT
Actuator
FL MAIN
To Stop Light
Master Cylinder
Front
Speed Sensor
P Valve
Stop Light Switch
Rear
Brake Cylinder
Front Brake Cylinder
Rear Speed Sensor

Fig. 2. ABS electrical and hydraulic systems. (Courtesy of Toyota)

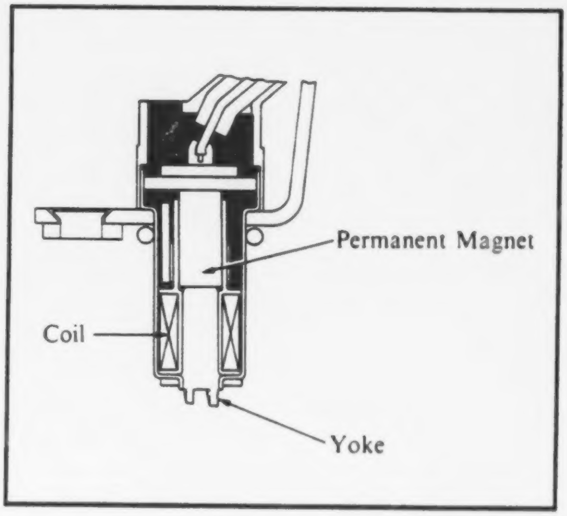


Fig. 3. Front wheel speed sensor. (Courtesy of Toyota)

The sensor that uses the permanent magnet and coil is shown in figure 3. Notice the yoke on the end of the sensor. The sensor is mounted on the steering knuckle with the yoke close to the rotor on the wheel.

The rotor has 96 serrations (fig. 4). The serrations will pass through the magnetic field from the sensor as they move by the yoke on the tip of the sensor.

If we show the waveform from the sensor on an oscilloscope, it would look like the drawing in figure 5. The movement of the serrations past the magnet causes a disruption of the magnetic lines of force, inducing a voltage as shown. The speed information is transmitted as the frequency of the signal. The higher the speed, the higher the frequency of the signal from the sensor.

The rear speed sensor (fig. 6) for the Toyota automobile does not use a yoke. The enlarged part of the drawing shows how the tip is made to bring the magnetic lines of force close to the moving serrations.

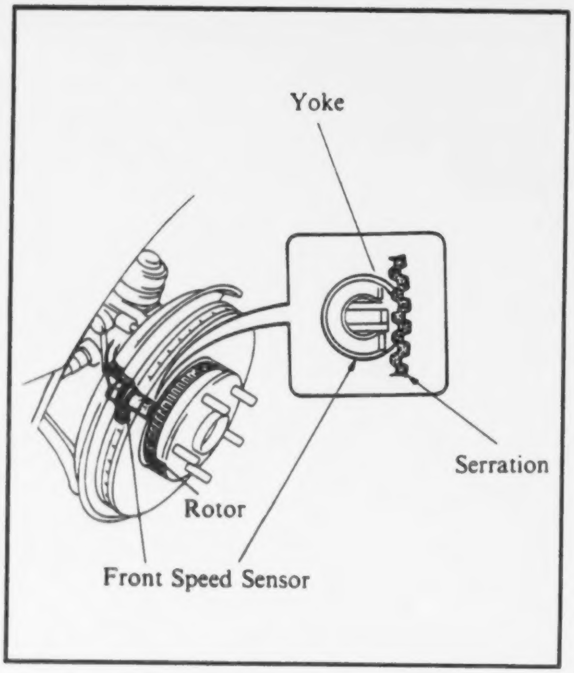


Fig. 4. Serrations mounted on rotor. (Courtesy of Toyota)

Since the rear wheels are controlled as a unit, some automobiles use a sensor on a common part of the transmission or axle. The Toyota Supra uses a sensor on the transmission extension housing (fig. 7).

This sensor is the same magnet and coil arrangement, except that the signal is sent to a processor which develops a pulse waveform from the sine wave received by the processor. This processor has an integrated circuit that computes the rear wheel speed based on the differential ratio and sends the correct frequency to the computer.

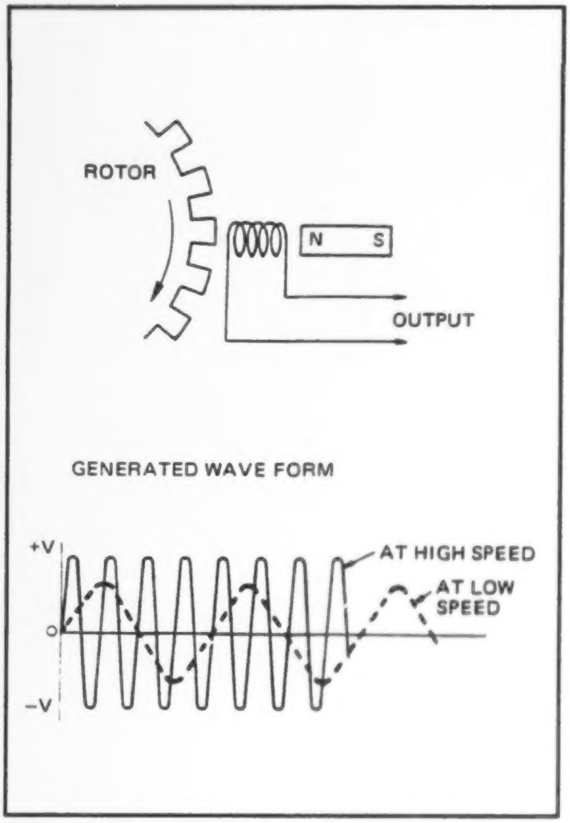

ROTOR
N
S
OUTPUT
GENERATED WAVE FORM
+V
0
−V
AT HIGH SPEED
AT LOW SPEED

Fig. 5. Serrations and sensor generate waveform. (Courtesy of Toyota)

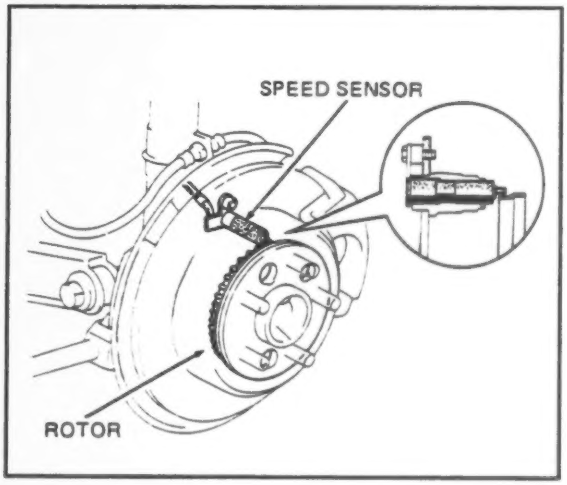

SPEED SENSOR
ROTOR

Fig. 6. Rear wheel speed sensor. (Courtesy of Toyota)

A sensor that is used to adjust the antilock action for the type of road surface is the "deceleration sensor." This sensor detects the rate at which the vehicle is slowing down. The computer is able to compare the reading from this sensor with the rate at which the wheel is slowing down and determine the road surface.

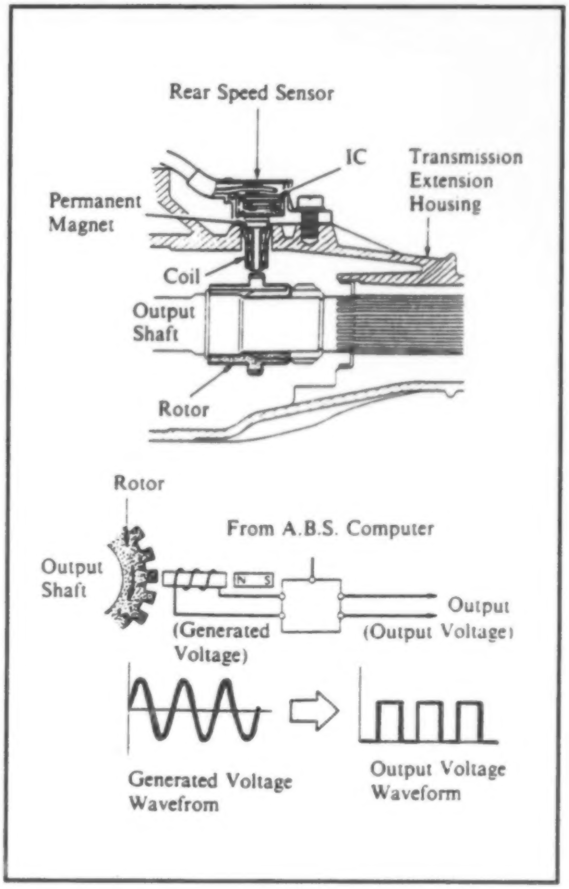

Rear Speed Sensor
IC
Transmission Extension Housing
Permanent Magnet
Coil
Output Shaft
Rotor
Rotor
From A.B.S. Computer
Output Shaft
N S
Output
(Generated Voltage)
(Output Voltage)
Generated Voltage Wavefrom
Output Voltage Waveform

Fig. 7. Rear wheel speed sensor components. (Courtesy of Toyota)

On a loose gravel or muddy road, the wheel will slow down more rapidly and, if not corrected, will lock up more rapidly on dry pavement. The inputs from the deceleration sensor and the wheel speed sensors will tell the computer that this is happening when the

rate of slowing is less than the rate at which the wheel is slowing. When this happens, the computer will reduce the brake fluid pressure to avoid locking up the wheels.

The deceleration sensor has a plate with slits in it (fig. 8) that moves toward the front of the car when it slows down. LEDs (light-emitting diodes) shine through the slits, and light sensors on the other side detect the LEDs.

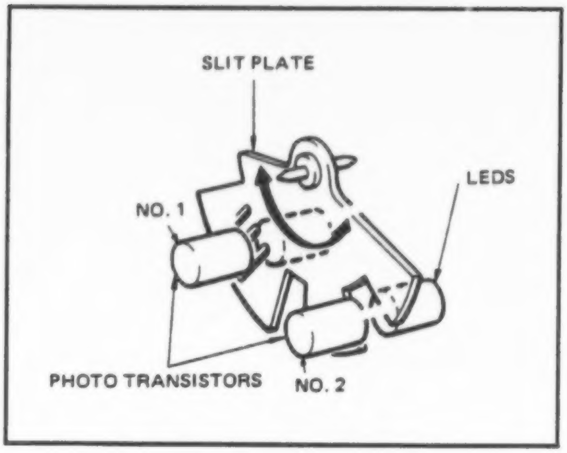


Fig. 8. Deceleration sensor components. (Courtesy of Toyota)

Figure 9 shows how the two LEDs are mounted to shine through the slit plate. The photo transistors mounted on the other side detect the light when there is a slit between the detector and the LED.

The plate will swing on its axis allowing some combination of the two lights to be detected. The position of the plate can be determined by the two LEDs, as shown in table 1. Notice that with a low-1 deceleration level, both lights will shine through slits in the plate. As the deceleration increases, the combination of which one is on and which is off changes. The computer is able to read this information as a two-bit binary number representing the amount of deceleration.

The actuator uses a three-position solenoid to control the brake fluid pressure to each wheel cylinder. Controlling the fluid pressure to the cylinder will control wheel speed. This solenoid valve has a coil and check valve in it. The computer will activate this valve in three steps, using either 0 amp, 2 amp, or 5 amp of current.

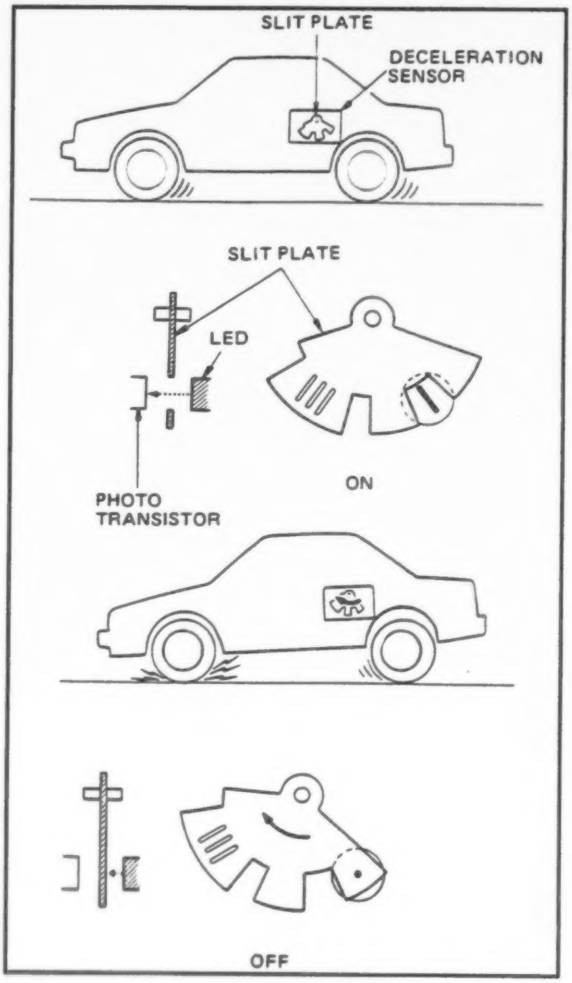


Fig. 9. Deceleration sensor operation. (Courtesy of Toyota)

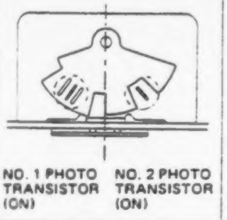
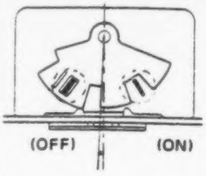
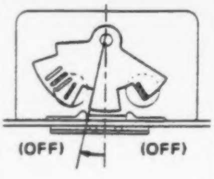
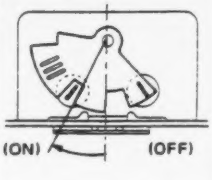
Rate of Deceleration	Low-1	Low-2	Medium	High
No. 1 Photo Transistor	ON	OFF	OFF	ON
No. 2 Photo Transistor	ON	ON	OFF	OFF
Position of Slit Plate	 NO. 1 PHOTO TRANSISTOR (ON) NO. 2 PHOTO TRANSISTOR (ON)			

Table 1. Deceleration rate level. (Courtesy of Toyota)

The three solenoid valves are shown in figures 10A-C. The status of the valve with 0 amp applied on the valve is shown in figure 10A. This is the pressure increase mode of operation. The spring in the valve has pushed the valve all the way to the bottom, closing port B as shown. Port A at the top of the valve is open, allowing brake fluid from the master cylinder to enter the valve and pass on to the braking system.

The holding mode is achieved when the computer sends 2 amp to the valve (fig. 10B). The 2 amp will pull the valve only partway against the spring. This will close both port A and port B and hold the pressure.

The valve in figure 10C shows the result of the computer feeding the full 5 amp to the valve. The valve has pressed tightly against the spring, closing port A and opening port B. This mode will allow fluid to escape from the valve and brake system and flow into the reservoir. As a result of putting some fluid into the reservoir, the brake fluid pressure will drop.

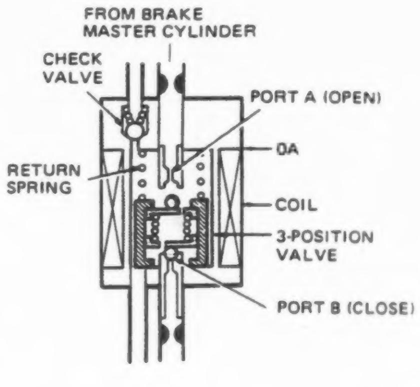

FROM BRAKE MASTER CYLINDER
CHECK VALVE
PORT A (OPEN)
0A
RETURN SPRING
COIL
3-POSITION VALVE
PORT B (CLOSE)

Fig. 10A. Pressure increase mode. (Courtesy of Toyota)

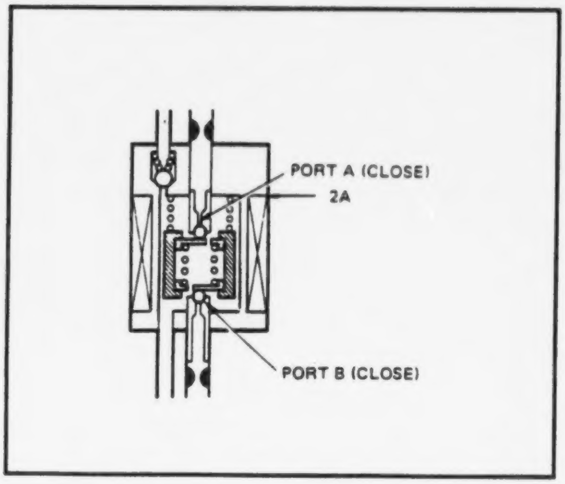

PORT A (CLOSE)
2A
PORT B (CLOSE)

Fig. 10B. Holding mode. (Courtesy of Toyota)

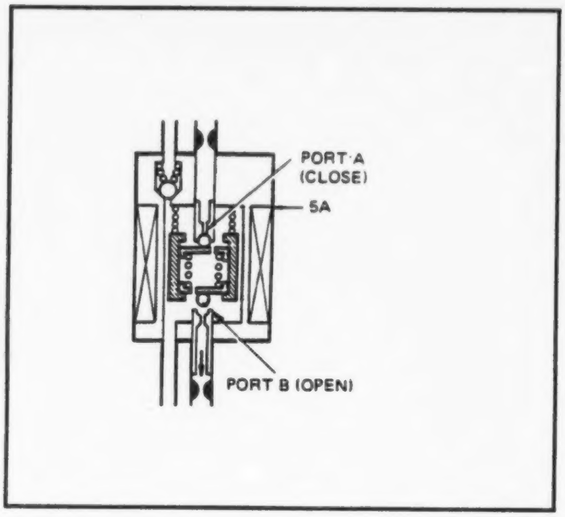

PORT A (CLOSE)
5A
PORT B (OPEN)

Fig. 10C. Pressure reduction mode. (Courtesy of Toyota)

A pump is used to return the brake fluid from the reservoir back to the master cyclinder, as shown in figure 11. The pump is always working when the antilock system is operating.

Notice how the cam at the top of the pump pushes the plunger, forcing the fluid back to the master cylinder. The reservoir stores the fluid between strokes of the pump.

Table 2 shows what happens when the antilock system is functioning. The graph at the top shows the vehicle speed compared with the wheel speed, the next graph shows the wheel deceleration rate, the graph next to the bottom shows the pressure modes on the three-position solenoid valve, and the bottom graph shows the brake fluid pressure.

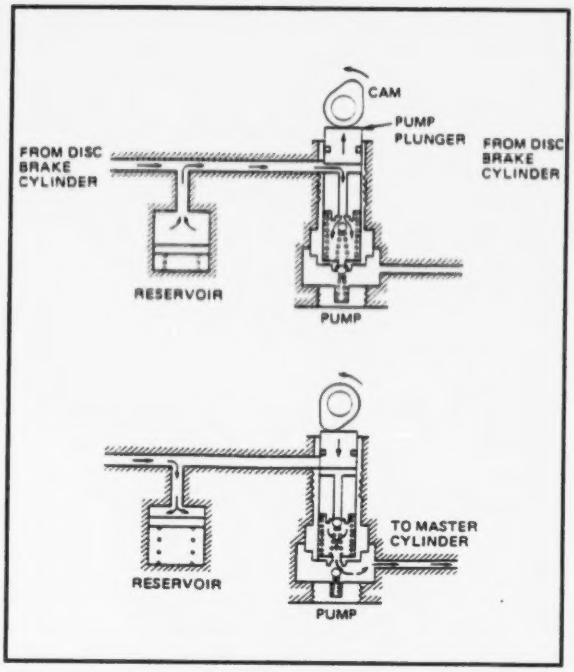

CAM
PUMP PLUNGER
FROM DISC BRAKE CYLINDER
FROM DISC BRAKE CYLINDER
RESERVOIR
PUMP
TO MASTER CYLINDER
RESERVOIR
PUMP

Fig. 11. Pump and reservoir for actuators. (Courtesy of Toyota)

Notice that column A shows wheel speed dropping, and the solenoid switches to pressure reduction mode. The bottom graph shows the pressure drops, and wheel deceleration reduces. The solenoid next goes into its holding mode, and the brake fluid pressure remains constant. Column B shows the solenoid alternating between holding and pressure increase as the wheel deceleration rate changes until at column C it does a pressure reduction again.

Antilock Diagnostics

The computer does a self-check of the system when the ignition is first turned on and the car is moving at least 4 mph. If a malfunction is found, the antilock light will go on, and a computer code will be stored in memory. The light can only be turned off by erasing the fault code out of memory.

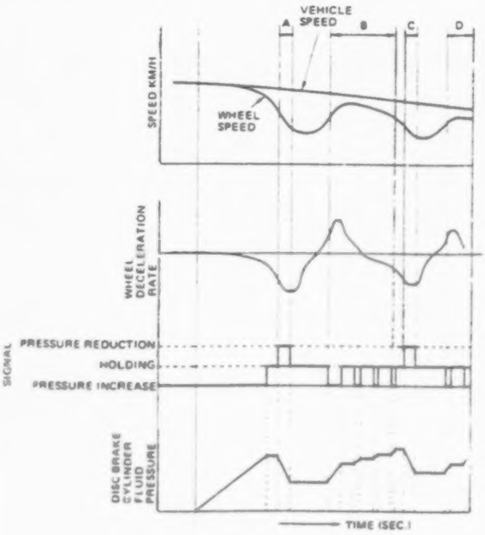


Table 2. Events cycle while the ABS is in operation. (Courtesy of Toyota)

If the system fails completely, the brakes will still continue to operate in the normal manner without the antilock feature.

To read the fault code in memory, first turn the ignition on, and then disconnect the actuator check connector (fig. 12). The fault codes stored in memory will be flashed on the antilock light.

The codes are read by counting the number of flashes. If there is no fault, the lamp will blink continuously at a rate of two times per second. If there is a malfunction, the lamp will remain off for the first 4 seconds, and then the first digit will begin. The lamp will blink the number before pausing for a 1-second pause. The next number will follow, and there will be another 4-second pause before it starts over. If there is more than one fault code, the code with the lowest number will flash first with a 2.5-second pause between codes and the 4-second pause before it starts over.

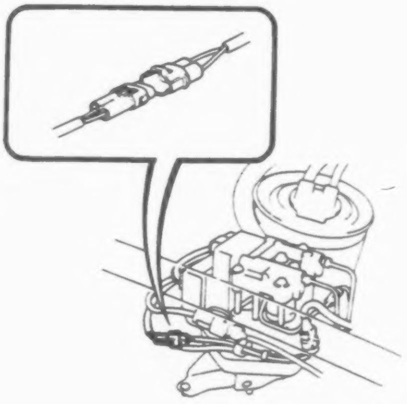


Fig. 12. Check connector location for a Supra. (Courtesy of Toyota)

After the system is repaired, the antilock light and the fault code in memory can be cleared by turning the ignition on with the actuator check connector disconnected and pumping the brake pedal so the light comes on eight or more times within 3 seconds. This should clear the antilock light and remove the fault codes from memory.

Exercise

1. What is the minimum and maximum wheel slippage that should be allowed by a good antilock brake system?
2. If the front wheel of a vehicle is doing 10 revolutions per second, what frequency would be coming from the antilock brake sensor if the rotor has 96 serrations?
3. What three current levels are used to control the three-position solenoid valve?
4. How do you read the fault codes from memory on an antilock brake system?
5. How long is the pause before the antilock light starts repeating the fault codes?
6. After the antilock brake system is repaired, how can you clear the fault codes from memory and restore the antilock light?

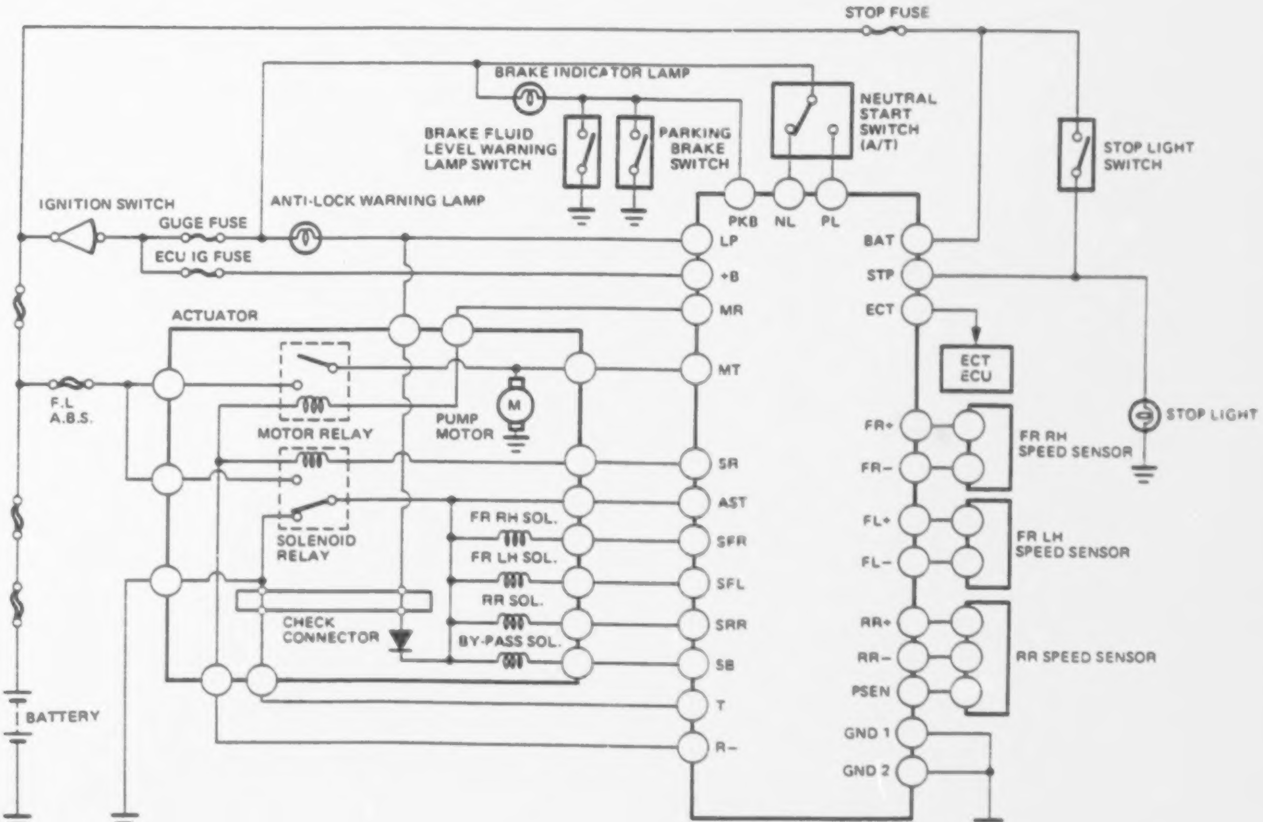
G-3 Antilock Brake Systems

Workbook

Essential Elements: **(gg) (1, 2, and 4)**

Figure 1 shows the electrical wiring for a Toyota Supra. Notice the three speed sensors on the right side of the computer. This system has four solenoids in the actuator, a motor relay, and a solenoid relay.

1. List the components that the current will pass through from the ignition switch to the SB input to the computer.
2. With the solenoid relay energized, what is the current path from the battery to the SFL connection on the computer?



STOP FUSE
BRAKE INDICATOR LAMP
NEUTRAL START SWITCH (A/T)
BRAKE FLUID LEVEL WARNING LAMP SWITCH
PARKING BRAKE SWITCH
STOP LIGHT SWITCH
IGNITION SWITCH
ANTI-LOCK WARNING LAMP
GUGE FUSE
ECU IG FUSE
PKB
NL
PL
LP
+B
MR
MT
BAT
STP
ECT
ACTUATOR
ECT ECU
F.L A.B.S.
MOTOR RELAY
PUMP MOTOR
M
STOP LIGHT
FR+
FR−
FR RH SPEED SENSOR
SR
AST
FL+
FL−
FR LH SPEED SENSOR
SOLENOID RELAY
FR RH SOL.
SFR
FR LH SOL.
SFL
RR SOL.
SRR
CHECK CONNECTOR
BY-PASS SOL.
SB
RR+
RR−
RR SPEED SENSOR
PSEN
BATTERY
T
R−
GND 1
GND 2
A.B.S. COMPUTER